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ABSTRACT

This analysis compares the efforts devoted to research and development (R&D) in education with those devoted to R&D in health and agriculture. Specifically, it characterizes the size and institutional arrangement of the educational R&D community and compares it on a common basis with the agricultural and medical R&D communities. The analysis is structured around performance in man-years of effort by institutional setting and sponsorship in dollars by institutional setting. The results indicate that, as compared with agriculture and health, research and development in education has the following characteristics: a) it has a much smaller proportion of the total value of production; b) it is sponsored almost entirely by the federal government; c) it is performed in much greater proportion at universities; and d) it is not performed by federal agencies. The report does not argue for more educational R&D but for a determination of the structural similarities and differences which exist in the agriculture, education, and health R&D systems as a preliminary to the ultimate objective of knowing how to improve systems for conducting R&D. (Included are appendixes of related charts and tables and a bibliography.) (Author/JA)

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A COMPARISON OF R&D SYSTEMS IN AGRICULTURE, EDUCATION, AND HEALTH

John Wirt

A WORKING NOTE
prepared for the

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

This Note was prepared to facilitate communication of preliminary research results. Views or conclusions expressed herein may be tentative and do not represent the official opinion of the sponsoring agency.

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PREFACE

This Working Note was written as part of the National Institute of Education planning effort conducted by The Rand Corporation for the Commissioner of Education. The NIE initiative stems from a belief that many of the problems in education today are a result of inadequate R&D in the past. It has been said that the system for conducting R&D is too small, too poorly distributed, and lacking in skills. In his message to Congress announcing the NIE legislation, the President mentioned how little has been spent on education R&D compared to other sectors of the economy.

While there is agreement on the need for improvements in education R&D, there is much less agreement on specifications for a set of R&D institutions which would achieve this improvement. Little work has been done which describes how to build capacity for conducting and using education R&D. We do not know what institutions should be doing how much R&D, nor do we know where they should be located. It seems plausible that simply granting project money to individual investigators will not produce the results in practice that hopes have raised. Simple forms like university research coupled with information abstracting services will not be enough. Mechanisms for linking R&D with practice will be crucial. In its early years NIE will be faced with some hard choices.

More knowledge on how to build better systems for conducting R&D would help, but such knowledge has proved difficult to find. Economists and others have nibbled at the edge of the problem for years. One means of attack on the knowledge deficit is to isolate natural experiments which yield insights into better ways of conducting R&D. This study is a step in that direction. It compares three R&D systems--agriculture, education, and health--with respect to the amount of R&D activity sponsored and performed by various institutional settings. The next steps, which this study does not take, are to expand the search to other sectors, and to correlate the descriptions obtained with measures of effect. Success is not guaranteed, and it will most certainly be difficult. One favorable factor will be the large differences which exist among R&D systems.

SUMMARY AND CONCLUSIONS

This analysis compares the effort devoted to R&D in education with that devoted to R&D in health and agriculture. It shows that in terms of both absolute level of R&D effort and R&D effort as a percentage of sector contribution to GNP, education is considerably less well supported than health or agriculture.

The comparatively low level of educational R&D may be seen by examining four different pictures for agriculture, education, and health for FY 1968. These pictures are:

(1) The *man-years* of research, development, and innovation activity *performed* in each of the possible institutional settings,

(2) The *dollars* of research and development *performed* in each of the institutional settings,

(3) The *dollars* of research, development, and innovation *sponsored* by each of the institutional sources, and

(4) The contribution of gross national product in each sector.

The picture of educational R&D performance by man-years is also shown for fiscal year 1965 to indicate the impact that the Elementary and Secondary Education Act of 1965 has had on educational R&D.

Specifically, it can be concluded that in FY 1968 (see Table 1):

(1) The contribution to gross national product was roughly the same in agriculture, education, and health,

(2) No more than one-fourth as many dollars were spent on *research* in education as in health or agriculture, and

(3) No more than one-fifth as many dollars were spent on *development* in education as in health or agriculture.

As Table 2 shows, the *ratio of development to research sponsorship* is higher in education (.85) than in health (.66), but lower than in agriculture (1.09) or the economy as a whole (1.74). The emphasis on development in education is a recent phenomenon, however; since before the passage of ESEA in 1965, the ratio of development to research expenditures was much lower.

Table 1

R&D ACTIVITY IN AGRICULTURE, EDUCATION, AND HEALTH

SECTOR	SECTOR NATIONAL PRODUCT, FY 1968 (in billions)	DOLLARS OF SPONSORSHIP (in millions)			
		Res.	Dev.	Inno.	Total
Agriculture	$ 73.5	$ 380	$410	$240	$1030
Education	$ 53.0	$ 90	$ 80	$ 70	$ 240
Health	$ 51.5	$1400	$1000	*	$2400

* No activity devoted to innovation was included.

Table 2

RATIO OF DEVELOPMENT SPONSORSHIP TO RESEARCH SPONSORSHIP, FY 1968

	Research Expenditure (in millions)	Development Expenditure (in millions)	$\frac{\text{Development}}{\text{Research}}$
Education	$ 90.	$ 80.	.85
Health	$ 1,400.	$ 1,000.	.66
Agriculture	$ 380.	$ 410.	1.09
All Sectors	$ 10,000.	$ 17,400.	1.74

The comparison of *R&D funds by sponsoring institution* (see Table 3) shows that educational R&D is very different from other R&D activities in that government supplies 88 percent of the educational R&D funds; while in the health field, government supplies 67 percent of the R&D funds; and in the field of agriculture, 42 percent. For all fields, 57 percent of the R&D funds is supplied by government.

Table 3

SOURCES OF R&D FUNDS, FY 1968

(millions of dollars)

SECTOR	FED. GOVT. SPONSORED	STATE & LOCAL	ALL OTHER	FED. AS % OF TOTAL	GOVT. AS % OF TOTAL
Education	$ 150	$ 2	$ 20	87	88
Health	$ 1,530	$ 70	$ 800	64	67
Agriculture	$ 210	$ 120	$ 460	27	42
All Sectors	$ 15,000	$ 500	$11,900	55	57

A comparison of *R&D communities by performing institutions* produces equally striking differences. Education is unlike health, agriculture, and the economy as a whole in that neither the Federal government nor industry performs much of the R&D in the sector (see Table 4). In all other sectors, at least 13 percent of the R&D dollars are consumed by the federal government, and at least 29 percent by industry. Another difference is that in education 60 percent of the R&D dollars is spent at colleges and universities, while in health the figure is 36 percent, in agriculture 28 percent, and in the economy as a whole 12 percent.

Table 4

EXPENDITURE OF R&D FUNDS BY PERFORMER, FY 1968*

SECTOR	UNIVERSITIES & COLLEGES	FEDERAL GOVT.	INDUSTRY	ALL OTHER	TOTAL
Education**	$ 110 (60%)	$ 2 (1%)	$ 10 (4%)	$ 70 (35%)	$ 190
Health	$ 874 (36%)	$ 362 (15%)	$ 695 (29%)	$ 465 (19%)	$ 2,396
Agriculture	$ 173 (22%)	$ 159 (20%)	$ 460 (58%)	$ -- (0%)	$ 792
All Sectors	$3,400 (12%)	$3,600 (13%)	$ 19,250 (70%)	$ 1,100 (4%)	$27,350

* Totals do not add exactly as a result of round-off approximations.

** Some innovation expenditures are included in the education category ($17.0 million), mostly in the university setting.

Table 5 shows performance of RD&I by institutions in man-years of effort. Note that while 15,000 man-years of effort are devoted directly to *innovation activities in agriculture*, only 1,300 man-years of such activity are applied in education. No separately identifiable innovation was included in health.

Table 5

PERFORMERS OF RD&I, FY 1968 (MAN-YEARS OF EFFORT)

Field and Type of Activity	Federal Government	Colleges & Universities	State & Local Agencies	Non-profit Institutions	Private Firms	Other Performers	Total*
Agriculture							
Research	2,090	2,360	0	**	7,950	0	12,400
Development	2,230	3,040	0	**	7.950	0	13,220
Innovation		4,000	11,000	0	0	0	15,000
Total	4,320	9,400	11,000	0	15,900	0	40,620
Education							
Research	80	1,210	470	200	40	50	2,040
Development	10	920	570	800	80	260	2,630
Innovation	5	790	270	120	30	90	1,300
Total	95	2,920	1,310	1,120	150	400	5,970
Health							
Research & Development	10,350	24,090	***	9,230	10,690	3,920	

* Totals do not add exactly as a result of round-off approximations.

** Some activity exists, but the amount is negligible compared with other entries in agriculture.

*** Included in other performers. Amount is very small.

CONTENTS

I. INTRODUCTION

OBJECTIVES OF THIS STUDY

The objective of this study is to characterize the size and institutional arrangement of the educational R&D community, and to compare it on a common basis with the agricultural and medical R&D communities. In brief, the results are that--as compared with agriculture and health--research and development in education is:

- far less a proportion of the total value of production,
- sponsored almost entirely by the Federal government,
- performed in much greater proportion at universities, and
- not performed by Federal agencies.

The data also show that the agriculture, education, and health sectors are similar in that a substantially smaller proportion of the total R&D expenditure is spent on development than in the nation's R&D effort as a whole.

The purpose here is not to argue for more educational R&D, or for more R&D at the local level, etc., for differences in distribution of effort among R&D systems is not intrinsically undesirable. The purpose is to determine the structural similarities and differences which exist in the agriculture, education, and health R&D systems as a preliminary to the ultimate objective of knowing how to design improved systems for conducting R&D. The next step towards this ultimate objective is to correlate the similarities and differences detected here with the record of success and failure in the same systems, and then draw conclusions. Undoubtedly, more studies of similarities and differences in more sectors and in more detail than here will also be required.

The structural differences among the R&D systems treated in this study are very large in some respects, raising the prospects that much can be learned from intra- and intersectoral comparisons of R&D systems. Furthermore, very little study of this type has been undertaken in the past. Most R&D systems have grown in piecemeal fashion through response to a myriad of internal pressures, but have rarely been subjected to systemwide evaluations. Overcoming this shortsightedness seems to offer substantial prospect for learning how to design better systems for conducting R&D.

In addition to comparing research and development activity, this study compares effort made to stimulate the adoption of R&D results. Looking at research and development alone would be a partial view, for broad scale utilization of R&D results is not solely a consequence of R&D success, but depends also on the systems which link R&D with practice. Except in industry and agriculture, however, very little emphasis has been placed on building linkages between R&D and practice.

Linking R&D with practice can involve a complex of activities. Among those which have been used are demonstrations, disseminations, and retraining programs. The entire complex of activities has been described by terms like: *diffusion of knowledge, implementation,* and *utilization of knowledge,* but each of these carried a one-way connotation that seems to limit the scope of activities involved in linking R&D with practice. Instead, this study will employ the term *innovation,* because it has been defined as the "act of introducing something new 'as the driving force in practical economic advance.'"[1] Often innovation is taken to include research and development as constituent activities, but here its meaning is restricted to the introduction of new products into use and not to the creation of these new products. For the three activities as a whole, the acronym *RD&I* will be used.

STRUCTURE OF THIS STUDY

Some dimensions of our agricultural, educational, and health R&D systems will be established by describing RD&I activity in agriculture, health, and education from two points of view.

(1) *Performance* in man-years of effort, by institutional setting; and,

(2) *Sponsorship* in dollars by institutional setting.

A distinction is made between performers and sponsors because the set

[1] *Webster's New International Dictionary,* G. & C. Merriam Co., Publishers, Springfield, Mass., 1966.

of performing institutions in each sector is different from the set of sponsoring institutions. Performance is described in man-years of effort instead of dollars to provide a basis for comparison which is independent of salary differentials and equipment expenditures. Sponsorship is quoted in dollars to provide a complementary measure. Another reason for working with man-years on the performance side and dollars on the sponsorship side is that independent sources of data for manpower on the sponsorship side are available for educational R&D. When separately analyzed, they provide a check on the accuracy of the education data. Both the sponsors' view and the performers' view are subdivided by research, development, and innovation since each contributes differently to the RD&I process.

The education performers data are presented for two time periods, FY 1965 and FY 1968, to show the differential effect of expenditures for RD&I under Title III, IV, and V of the Elementary and Secondary Education Act (ESEA) of April 1965. It will be shown that these titles made possible a 50 percent increase in the man-years of educational R&D performed in 1968 over 1965.

The RD&I activity included in this study encompasses all endeavors *formally organized* to achieve increases in productivity; whether this involves acquiring new knowledge (research), creating new products or management systems (development), or diffusing these results into practice (innovation). The distinction "formally organized" is important because it eliminates unsystematic and unplanned improvements such as suggestion-box developments contributed by on-the-job employees, or action grant programs devoid of experimental controls or design.

TREATMENT OF UNCERTAINTY

There are two sources of uncertainty in the results to be presented. There is, first, *the imprecise nature of manpower and expenditure data.* This uncertainty derives from the ambiguities which unavoidably occur in assigning activities to research categories, no matter how precisely they are defined. Whether an activity is research, development, or neither, is often uncertain. Similarly, the distinction between agriculture-related, education-related, and health-related research can be unclear.

The second source of uncertainty is that *data are not available in the same format across sectors*, necessitating transformation of some data to another format. The constants of transformation were not always available in the complete detail desired, making it necessary to construct approximate transformations from the pieces of information that were available.

A new method of quantitatively describing these uncertainties was derived and used throughout the report. The method is an application of the "subjective interpretation" of probability theory, and provides a means for displaying the precision which underlies the estimates of RD&I activity. A derivation of this method appears in Appendix A.

Of the three sectors--agriculture, education, and health--the data for agriculture are the most precise because they were obtained from a management information system specifically designed to collect these data. The data for education performance are the least precise because they were obtained from a partial survey of the educational R&D community and rescaled to account for uncovered populations. In each sector the data on industry are less certain than the data for government and universities, since industry has not been as carefully linked into government information agencies.

Without exception, the total R&D effort reported for an institution is a more certain figure than the research or development figure for that institution since source data often did not distinguish level of effort by research activity. In such cases, transformations were derived from auxiliary data sources to divide the aggregates into *RD&I* activity components.

The uncertainties just discussed are distinct from errors introduced by omitting entire segments of activity. In the research and development classes of activity, the data utilized are thought to include all segments of activity, even though some uncertainty remains in tallying activity within a segment. In the innovation class, however, only some of the segments which serve an innovation function have been included.

AGENDA OF THIS REPORT

Section II specifies the criteria for inclusion of an activity in the various categories defined earlier in this section. Section III presents and compares the results for the performers' side. Section IV provides the same treatment for the sponsors' side. The value of production in each sector and national totals of R&D sponsorship in all sectors together are also presented in Section IV. Section V contains commentary on some of the study's results.

II. DEFINITION OF RESEARCH ACTIVITIES, SPONSORS, AND PERFORMERS

RANGE OF ACTIVITIES INCLUDED IN EACH SECTOR

The *agriculture sector* is defined as all production activities which consist of harvesting or transforming a plant, animal, or fish crop.[1] This includes timber and forest products manufacture, crop growing, textile weaving, tobacco, and farm animals. R&D activity is included in the agriculture sector if it is supported by an institution or industry producing in the agriculture sector, or is supported by an institution clearly devoted to agricultural objectives. Agricultural R&D includes knowledge-building and development activities directed toward conserving and developing the use of soil, water, and related resources; protecting man, plants, and animals from loss, damage, or discomfort caused by natural hazards; increasing the efficiency of products and markets and improving their quality; developing new products and processes; and improving the level of human nutrition.

The *education sector* is defined to include preschool, elementary, secondary, and higher education services. Also included are services provided by private sector firms such as: secretarial schools, electronics institutes, language schools, and in-service training to employees.[2] As in agriculture, R&D activity is included as part of the education sector if it is supported by an institution producing educational service, or is supported by an institution which is clearly and primarily devoted to the objectives of the education sector.

The *health sector* is defined to include production of pharmaceuticals, ophthalmatic and orthopaedic products, physician, dental, and psychiatric services, public and privately controlled clinical services, and the provision of health insurance.[3] As in the two previous sectors, activity is included as health R&D if it is supported by an industry or institution producing health services, or by an institution

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[1] Standard Industrial Classification Codes (SIC), 01, 07, 08, 09, 20, 21, 22, 24, and 26.

[2] SIC code 82.

[3] SIC code 80.

clearly devoted to health objectives. Thus, research on human nutrition is counted as agriculture R&D if supported by the U.S. Department of Agriculture but as health R&D if supported by the National Institutes of Health.

The health and education sectors are similar in that consumption occurs at the point of production and thus distribution cannot be separated from production in measuring the scale of activity. The situation is different in agriculture where production and consumption are usually separated by an extensive distribution system. In specifying the scale of activity in the agricultural sector, accounting will stop at the point where production ends and distribution begins.

DEFINITION OF RESEARCH ACTIVITY CLASSES

Precise definitions of research and development have been attempted by many authors, but in using them to sort project activity, some ambiguity always remains. The principal difficulty lies in finding a criterion for distinguishing between research and development, for the line between innovation and R&D is relatively easy to draw.

The innovation class of activity includes all actions expressly undertaken to link R&D activity with practice. Innovation includes informing target communities about existing R&D solutions and programs, demonstrating the effectiveness of solutions and programs, and training target communities in their use. It also includes the relay of concerns and difficulties back to researchers and developers and the servicing and nurturing of installed solutions and programs. Thus, an activity will be labeled "innovation" if the following criterion is satisfied.

> Criterion for Innovation. Any activity whose purpose is to encourage utilization of R&D results by practitioners; and/or to relay problems and deficiencies back to the R&D community.

Development is the creative process of inventing new products, systems, or procedures which practitioners can use to improve productivity or fill a perceived need. Developmental activity typically begins with determination of design objectives, and then proceeds in a disciplined way through iterative stages of synthesis, construction, and testing until a satisfactory result is obtained. Adjustment of the objectives during development may occur, but the final results will essentially match the original specification. As a final stage, the developed product is subjected tc a thorough trial and evaluation in its intended environment. Developmental activity can be viewed as including three subcategories: (1) *operational development,* which is the invention of procedures or systems for solving operating problems; (2) *product development,* which is the creation of material products for use, and (3) *testing and evaluation,* which is the verification that a proposed solution or invention works as intended.

As much as any characteristic, development is typified by (1) its orientation towards inventing something which meets a practical need, and (2) the prudency of field-evaluating the final product. Thus an activity will be called "development" if the following criterion is satisfied.

> Criterion for Development. Any activity whose purpose is (1) inventing a product, system, or procedure which practitioners can use to improve performance, or (2) performing a field-evaluation of a developed product, system, or procedure.

In general, research is the process of discovering explanations for observed phenomena through identification of the critical variables and the relationships among them. A variety of methods are used in doing research, among them are experimentation, which is controlled testing of theories or proposed solutions; naturalistic observation, which is intuitive, exploratory analysis; and deductive reasoning, which is fabrication of axiomatic premises and their logical results. Problems are selected in research more on the basis of solubility than satisfaction of practical needs. Research output is evaluated and consumed largely by the research community itself, unlike the products of development which are consumed by practitioners.

Two subcategories of research are *basic* and *mission-oriented research.* Research that is undertaken in order to answer a question arising from development work, or research whose results might affect a decision in development projects is often called mission-oriented research. Research done primarily to add to the store of knowledge without regard for its practical efficacy is often called basic research. Basic research results may alter perceptions and lay the foundation for major changes, but in themselves rarely affect current decisions. No attempt to separate research activity into the basic and mission-oriented subcategories was made in this study, since the required data were lacking in all three sectors.

Policy evaluation, program evaluation, and assessment evaluation are included in the research category of activity in this study. Policy evaluation is the analysis of strategic alternatives for decision-makers. Program evaluation is the exploration, analysis, and measurement of an educational program or programs at the local, state, and national level. Assessment evaluation is measuring the state of affairs in some area of concern. Ideally, this evaluation activity should be tallied in a separate category, but the format of available data did not allow this distinction.

The distinction between research and development can be clarified by giving some examples. The discovery that poliomyelitis is caused by a particular virus was a result of research activity, while the search for and validation of a polio vaccine against this known virus was largely development. Efforts to produce corn that is more resistant to a particular disease are development, but studying the mechanisms of action of herbicides is research. A project to determine the factors which affect enrollment in adult education courses is research, while a project to devise a curriculum for an adult education course is development.

While all of the data sources used in this study have used criteria for research, development, and innovation equivalent to the ones just given, the method of sorting project activity into these classes varied somewhat. In education, activity has been sorted by Clark and Hopkins (1969)[1] according to definitions (see Table 1) very much like the ones here. They examined the role of each professional contributing to a research project, and then assigned his work to the class in which

[1]See the Bibliography, p. 97.

Table 1·
DEFINITIONS OF RESEARCH ACTIVITY MODES

SECTOR AND MODE	PERSON(S) SORTING ACTIVITY INTO MODES & CRITERIA USED
AGRICULTURE, Performance & Sponsorship	*Author of this study.*
Research Basic research Mission-oriented research	All activity formally organized to pursue the objective of increasing knowledge, and/or improving productivity (RD&I activity), but not classed as development or innovation.
Development Operations development Product development Testing and Evaluation	All RD&I activity which produces output intended to improve performance in practice including extensive field or clinical evaluation of that output before its distribution to users.
Innovation	All RD&I activity having the purpose of encouraging utilization of R&D results by practitioners.
EDUCATION, Performance[1]	*Clark and Hopkins, 1969.*
Research	
Basic Research	"The objective of this activity is to add to what is known in the social and behavioral sciences. The investigator may or may not see the content of his work as relevant to education.
Mission-oriented research	"Investigating educationally oriented problems. Conducting social bookkeeping."
Development	
Operations development	"Inventing solutions to operating problems."
Product development	"Engineering packages and programs for educational use."
Testing and Evaluation	"Concern of evaluation is development and application of criterion measures which can be used to assess the efficacy of proposed solutions and programs."
Innovation	"Informing target systems about solutions and programs. Demonstrating the effectiveness of solutions and programs. Demonstrating the effectiveness of solutions and programs. Training target systems in the use of solutions. Servicing and nurturing installed solutions and programs.
EDUCATION, Sponsorship[2]	*USOE, 1969, and author of this study.*
Research	"The objective or research activities is to discover, reinforce, or refine knowledge. Research is carried out because we want to devise better conceptual models for describing inter-relationships among variables, or because we want to establish a direction and nature of so called 'cause and effect' interaction."

Table 1 (cont'd)

SECTOR AND MODE	PERSON(S) SORTING ACTIVITY INTO MODES & CRITERIA USED
Development	"The objective of development activities carried out in the field of education is to produce materials, techniques, processes, hardware, and organizational formats for instruction. The basis for such development is our knowledge about learning, motivation, instruction, and education. The materials and techniques developed are designed to accomplish certain objectives, specified in advance, which are construed to be part of the broader goals of instruction or education."
Innovation	Dissemination, and diffusion of educational products and solutions into practice. Also includes demonstrations.
HEALTH, Sponsorship[3]	*Employees of the sponsoring agency.*
Research	"Systematic, intensive study directed toward fuller scientific knowledge or understanding of the subject studies."
Basic research	"Investigator is concerned primarily with gaining a fuller knowledge or understanding of the subject under study."
Mission-oriented research	"Investigator is primarily interested in a practical use of the knowledge or understanding for the purpose of meeting a recognized need."
Development Operations research Product development Testing and Evaluation	"Systematic use of the knowledge and understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and proceses."

Sources of the criteria:

[1] Clark and Hopkins, 1969; p. 30

[2] U.S. Office of Education, 1969: pp. 1, 3, 4.

[3] National Science Foundation (NSF-31), 1969; p. 95.

he spent the most time. In health, the National Science Foundation (NSF-31, 1969) asked program analysts in industry and the agencies to sort their own institutions' research activity according to definitions established by NSF (see Table 1). Whether sorting was actually done at the individual or the project level could not be determined. In agriculture, the U.S. Department of Agriculture asked the researchers themselves to apportion their time and dollars into each of several research goals laid down by USDA. The division of activity in each goal into the RD&I classes was subjectively estimated by the author of this study.

CATEGORIES OF SPONSORING INSTITUTIONS

Table 2 describes this study's coverage of sponsoring institutions in general terms, and lists sponsors by name to the extent possible. The list of names is not exhaustive in each category of sponsors, since specific names are not available uniformly across all the categories. This unevenness is inherited from the data sources and cannot be reduced except at great expense.

The grouping of sponsoring institutions into institutional settings is largely determined by the format of data sources, but an attempt was made to separate profit from nonprofit sources, government from nongovernment, and government by level. Federal government sponsors are listed individually if their mission is primarily directed to the sector in consideration, or sometimes in the residual category ("Other Federal Agencies") if their mission is primarily in service of another sector.

Sponsorship is measured in dollars of total expenditure for research activities including project management, sub-professional personnel and secretarial costs, and purchase of equipment. Construction monies are not included nor are management costs at the Federal level. Federally sponsored research in industry includes all overhead costs, but many overhead services such as those produced by Government Services Administration are not included in sponsorship of government research. Whether or not overhead costs are included in industrially sponsored industrial research and development was not determined.

Table 2

CATEGORIES OF SPONSORS

SECTOR	SPONSORS	COVERAGE OF THE DATA SOURCES UTILIZED: RESEARCH & DEVELOPMENT	COVERAGE OF THE DATA SOURCES UTILIZED: INNOVATION
AGRICULTURE			
State Government	State Agriculture Depts.	All appropriations for State Agriculture Experiment Stations are included.	All appropriations for extension service are included. Nothing else.
USDA	Agriculture Research Service Economic Research Service Forest Service Statistical Reporting Service Farmers Cooperative Service Cooperative State Research Service. PL. 480 Funds Extension Service	All appropriations for intramural and extramural research and State Agric. Experiment Stations by these agencies are included.	All appropriations for extension service are included. Nothing else.
Industry	Unknown, but mainly in agricultural chemicals and biologics, farm machinery, food processing and new product development. Private foundation support is also included.	**Expenditures estimated by USDA by exhaustive tabulation of Science Information Exchange (SIE) abstracts. Estimates not revised to account for non-respondents.**	No expenditures are included.
Other University & Federal Agencies	Higher education institutional funds **Dept. of H.E.W.** **Atomic Energy Commission** **National Science Foundation** **Other Federal Agencies**	**Expenditures estimated by USDA by exhaustive tabulation of SIE abstracts, and Federal appropriations for agriculture-related basic science. No compensation for non-respondents.**	No expenditures are included.

Table 2 (cont'd.)

SECTOR	*SPONSORS*	*COVERAGE OF THE DATA SOURCES UTILIZED* *RESEARCH & DEVELOPMENT*	*INNOVATION*
EDUCATION			
USOE	U.S. Office of Education	Appropriations for RD&I from ESEA (Titles III, IV, & V), NDEA, Vocational Education Act of 1963, Handicapped Childrens Act and Community Mental Health Centers Act of 1963 are included. Does not include research training or facilities and equipment grants.	
NSF	National Science Foundation	Appropriations by the Pre-college and Undergraduate Divisions for curriculum improvement and teacher institutes.	
OEO	Office of Economic Opportunity	Appropriations for research, demonstration, and evaluations thru Head Start, Follow Through, and Community Action Programs.	
Other Federal Agencies	National Institute of Mental Health National Institute of Child Health & Human Development Department of Defense National Endowment for the Arts and Humanities Department of Labor	Appropriations for education or education-related R&D estimated by USOE by exhaustive tabulation of SIE and Defense Documentation Center abstracts. Estimates revised to account for non-respondents.	No appropriations are included.
State Government	State Departments of Education	Appropriations estimated by the present author on basis of two surveys. Extent of undercoverage in innovation class of activity not clear.	
Private firms	Private firms	Expenditures estimated roughly by the present author.	No appropriates are included

Table 2 (cont'd.)

SECTOR	SPONSORS	COVERAGE OF THE DATA SOURCES UTILIZED: RESEARCH & DEVELOPMENT	INNOVATION
EDUCATION (cont'd.)			
Foundations and Others	Ford Foundation Carnegie Corporation Kettering Foundation Commonwealth Fund Danforth Foundation Esso Education Foundation Grant Foundation Maud Hill Family Foundation Mott Foundation Educational Testing Service National Education Association American Education Research Assn.	Expenditures estimated by USOE based on exhaustive survey of SIE and DDC survey. Compensation for non-respondents made.	
HEALTH			
NIH	National Institutes of Health	All appropriations for R&D included. No research training or facilities included.	No appropriations are included.
Other HEW & Vet. Admin.	Department of HEW Veterans Administration National Institute of Mental Health	All appropriations for health-related R&D included. No research training or facilities included.	No appropriations are included.
Other Federal Government	Department of Defense Atomic Energy Commission National Aeronautics and Space Administration Department of Agriculture Department of Commerce Department of State Department of Transportation National Science Foundation Tennessee Valley Authority	Appropriations for R&D estimated by NIH through discussions between agencies and NIH staff.	No appropriations are included.

Table 2 (cont'd.)

SECTOR	*SPONSORS*	*COVERAGE OF THE DATA SOURCES UTILIZED* RESEARCH & DEVELOPMENT	INNOVATION
HEALTH (cont'd.)			
Industry	Pharmaceuticals	Expenditures for R&D estimated by NIH staff through discussions with professional and industry associations and other sources.	No expenditures are included.
Foundations & Institutional Funds	Foundations Private contributions Endowment Institutions' own funds	Expenditures for R&D estimated by NIH staff.	No expenditures are included.

CATEGORIES OF PERFORMERS

Performance will be measured in man-years of effort instead of numbers of positions, people, or dollars--in the judgment that level of effort is thus most accurately represented. Especially in education, the choice of man-years of effort instead of people or positions is significant since much of the R&D effort occurs on a part-time basis (Clark and Hopkins, 1969, p. 103). The choice of man-years of effort instead of dollars expended is significant, since salaries are higher in health R&D than in education and agriculture (probably because of competition from medical doctors' salaries).

To qualify for inclusion in the performer tables, an activity must be at the "professional level." In agriculture this is defined to be all research work "at the 'rank' of assistant professor or above," or GS-11 or above. Research administrators are not included (U.S. Department of Agriculture, 1967; p. v.). In education, "professional level" excludes secretarial and clerical effort, and administration performed by people who are primarily administrators; but it includes all people trained in a specialty relevant to the research activity. Statisticians and programmers, for example, are included in the education performer data. A director of audio-visual services is included if he does experimental work, but not otherwise.[1] In health, the professional level includes work by "M.D.s and Ph.D.s and others with less than doctoral training who functioned as principal investigator and collaborators. In general, this does not include persons with such training who performed as research assistants; it also excludes technicians and all other supporting personnel" (U.S. Office of Resource Analysis, 1969).

Just as for sponsors, performers were grouped by institutional setting in which work was performed. A description of the performance covered in this study along with specific names where possible appears in Table 3. Ideally, a list of the performers included in each category should be given, but this information was not available from the data sources.

It should be commented that quality of RD&I performed was not a qualification for inclusion in the performer tables. Certainly, some

[1]Conversation with John Hopkins, co-author of Source C.

Table 3

DEFINITION OF PERFORMER CATEGORIES

SECTOR *INSTITUTIONAL SETTING*	*PERFORMERS*	*COVERAGE OF THE DATA SOURCES UTILIZED* *RESEARCH & DEVELOPMENT*	*INNOVATION*
AGRICULTURE			
Colleges & Universities	R&D activity in 53 State Agricultural Experiment Stations, 10 Forestry Schools, and 12 other cooperating institutions.	All performance sponsored by USDA or state government is included	Nothing included.
USDA	R&D activity in federal laboratories and field stations or funded extramurally. Over 95 % intramural.	All performance sponsored by USDA research agencies listed in Table 2 is included.	All extension and county agents only included.
Industry	R&D activity in divisions of profit making firms. This activity is heavily concentrated in agricultural chemicals and biologics, farm machinery, food processing and new product development.	Performance estimated by USDA by exhaustive tabulation of SIE abstracts. No revision for non-respondents made.	No performance included.
Other University & Federal Agencies	R&D conducted in higher education science departments such as botany and zoology and in government. "This research is not done specifically for agriculture," but is potentially relevant to its goals. Much of this research is supported and/or performed by Federal agencies such as NIH, AEC, and NSF.	Performance estimated by USDA by exhaustive tabulation of SIE abstracts. No revision for non-respondents.	No performance included.

Table 3 (cont'd.)

SECTOR INSTITUTIONAL SETTING	PERFORMERS	COVERAGE OF THE DATA SOURCES UTILIZED: RESEARCH & DEVELOPMENT	COVERAGE OF THE DATA SOURCES UTILIZED: INNOVATION
EDUCATION			
Universities and Colleges	All R&D activity in colleges and universities of immediate or potential relevance to education sponsored by an education agency.	Performance data in the education sector was obtained by transforming Clark and Hopkins' study of education RD&I manpower. Their estimates are revisions of data from a survey, the National Register of Educational Researchers. This survey attempted to tally all RD&I effort.	
State Agencies	R&D pertaining to education problems in State Departments of Education or in any other State Agency sponsored by an education agency.		
Professional Associations	R&D pertaining to education problems supported in professional public, or lay associations by an education agency, or by professional education associations.		
Local School Agencies	R&D pertaining to education problems performed in public school districts or in public schools.		
Firms and Private Research Institutes	R&D on education problems in profit and nonprofit making education-related firms.		
Education Laboratories	R&D activity in the Regional Education Laboratories supported by the Office of Education.		

Table 3 (cont'd.)

SECTOR INSTITUTIONAL SETTING	*PERFORMERS*	*COVERAGE OF THE DATA SOURCES UTILIZED*	
		RESEARCH & DEVELOPMENT	*INNOVATION*
HEALTH			
Federal Laboratory	Federally performed intramural R&D on clinical problems and in the life and psychological sciences of potential relevance to medicine. NIH, NIMH and the Veterans Administration are principal performers.	Performance is derived from data on health sponsorship. Therefore, all performers supported by sponsors in Table 2 are included. No other performance is included.	No performance is included.
Universities and Colleges	R&D activity of potential relevance to the solution of health and clinical problems, principally in the life, psychological, and clinical sciences, that is sponsored by a health agency and performed in an institute of higher education or its allied research institutes.	"	"
Nonprofit Institutions	Same activities as included in above except performed in medical clinics or non-profit research centers and supported by a health agency.	"	"
Industry	R&D on health-related problems conducted in profit-making firms. Most activity occurs in the pharmaceuticals industry.	"	"
Other Performers	Includes all foreign performers.	"	"

RD&I activity contributes more to capability than the rest, but, of equal certainty, there is no appropriate way to measure that contribution.

III. COMPARISON OF PERFORMER COMMUNITIES

COMPARISON BY INSTITUTIONAL SETTINGS

Estimates of total performance in the agriculture, education, and health sectors are shown in Tables 4 through 6. For each category of performance estimated, two numbers are shown; one is an "expected value" and the other, a "standard deviation." As explained in Appendix A, the expected value is an estimate of the actual performance in a category. The degree of uncertainty in this estimate is specified by quoting the standard deviation. The interpretation of these two numbers is as follows:

(1) With probability .35, the true value of the quantity being estimated lies between the expected value plus one-half standard deviation and the expected value minus one-half standard deviation.

(2) With probability .9, the true value of the quantity being estimated lies between plus and minus two standard deviations of the expected value.

Another interpretation of these quotations[1] is that if the true value of each quantity being estimated were known, then on the average 35 out of 100 true values would lie between the expected value plus one-half standard deviation and minus one-half standard deviation. Also, on the average, 9 out of 10 would lie within the expected value plus and minus two standard deviations.

As Tables 4, 5a, and 6 show, the largest share of R&D (not RD&I) is done by industry (61 percent) in agriculture, and by higher education institutions in education (45 percent) and health (41 percent). The second largest shares are conducted by universities (21 percent), and Federal laboratories (17 percent) in agriculture; by local school agencies (17 percent) and regional labs (17 percent) in education; and by industry (18 percent) and Federal laboratories (18 percent) in health.

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[1]Which applies only to the subtotals and totals.

Table 4

PERFORMERS OF AGRICULTURE R&D, FY 1968
(man-years of effort)

RESEARCH ACTIVITY	PERFORMERS BY INSTITUTION										TOTALS	
	USDA (intra-extramural)		County Agencies		Colleges & Universities (SAES)		Industry		Other Univ. & Federal Agcys.		Except Column 4 (Note)	
	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*
Basic Research & Mission-oriented Research	2,090	*357*	--	--	2,360	*526*	7,950	*2,360*	6,200	*1,860*	12,400	*2,440*
Operations development, product development, testing & evaluation	2,230	*357*	--	--	3,040	*526*	7,950	*2,360*	6,200	*1,860*	13,220	*2,440*
Subtotal	4,320	--	--	--	5,400	--	15,900	*1,560*	12,400	*1,220*	25,620	*1,560*
Innovation	--	--	11,000	*275*	4,000	*50*	--	--	--	--	15,000	*300*
TOTAL	4,320	--	11,000	*275*	9,400	*50*	15,900	*1,560*	12,400	*1,220*	40,620	*1,590*

Source: Appendix E, and U.S. Department of Agriculture, 1969; p. 58.

NOTE: USDA performance is over 95% of intramural.
Column 4 is not added into the totals since it represents basic life, and botanical, and zoological science work supported by HEW, AEC, and NSF not clearly related to agriculture. The work is performed in government and the universities.

Table 5a

PERFORMERS OF EDUCATION R&D, FY 1968
(man-years of effort)

RESEARCH ACTIVITY	PERFORMERS BY INSTITUTION																TOTAL	
	Universities & Colleges		State Agencies		Local School Agencies		U.S. Office of Education		Professional Education Associations		Other Associations		Private Research Institutions		Private Firms			
	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*
Basic & Mission-Oriented Research	1205	*408*	146	*126*	320	*85*	76	*16*	28	*30*	21	*14*	129	*76*	39	*20*	72	*44*	2037	*501*
Operational Research, Product Development, Testing & Evaluation	916	*286*	86	*58*	479	*110*	9	*5*	28	*22*	232	*103*	126	*75*	77	*35*	675	*140*	2630	*373*
Subtotal	2121	*553*	232	*141*	799	*144*	85	*18*	56	*38*	253	*105*	255	*111*	116	*42*	748	*147*	4665	*738*
Innovation	787	*216*	128	*81*	137	*53*	4	*3*	32	*22*	57	*34*	28	*81*	29	*18*	96	*44*	1300	*272*
TOTAL	2912	*629*	360	*104*	935	*139*	90	*17*	90	*24*	310	*122*	283	*108*	144	*53*	845	*132*	5970	*854*

Source: Appendix B.
NOTE: Not all totals add exactly due to round-off approximations.

Table 5b

PERFORMERS OF EDUCATION R&D, FY 1965
(man-years of effort)

RESEARCH ACTIVITY	PERFORMERS BY INSTITUTION																TOTAL	
	Universities & Colleges		State Agencies		Local School Agencies		U.S. Office of Education		Professional Education Associations		Other Associations		Private Research Institutions		Private Firms		Educational Labs.			
	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*	Mean	*Std.*
Basic & Mission-Oriented Research	1321	*177*	157	*122*	162	*51*	76	*10*	28	*30*	8	*13*	130	*72*	39	*19*	17	*17*	1938	*236*
Operational Research, Product Development, Testing & Evaluation	551	*147*	60	*57*	159	*64*	9	*5*	28	*21*	214	*92*	130	*72*	77	*33*	17	*13*	1244	*210*
Subtotal	1872	*230*	217	*134*	321	*82*	85	*11*	56	*37*	222	*93*	260	*102*	116	*38*	34	*22*	3182	*316*
Innovation	616	*110*	77	*80*	45	*40*	4	*3*	28	*21*	42	*32*	29	*81*	29	*17*	17	*13*	888	*169*
TOTAL	2493	*214*	294	*89*	366	*66*	90	*9*	85	*20*	264	*108*	288	*96*	144	*48*	51	*13*	4074	*286*

Source: Appendix A
NOTE: Not all totals add exactly due to round-off approximations.

Table 6

PERFORMERS OF HEALTH R&D, FY 1968
(dollars in millions)

SPONSORS	PERFORMERS										TOTALS	
	Federal Laboratory		Universities & Colleges		Nonprofit Institutions		Industry		Other Performers			
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
NIH	138.2	--	518.3	--	129.6	--	34.6	--	43.2	--	863.9	--
Other HEW	66.0	--	105.6	--	50.2	--	79.2	--	37.0	--	264.0	--
Veterans Admin.	45.0	--	.5	--	.5	--	--	--	--	--	46.0	--
Other Federal	113.0	--	116.5	--	24.7	--	91.8	--	7.1	--	353.0	--
State & Local	--	--	10.3	*10.8*	6.9	*6.9*	6.9	*6.9*	44.8	*15.5*	69.0	*6.9*
Industry	--	--	30.8	*30.9*	30.8	*30.9*	554.4	*43.0*	--	--	615.0	*62.0*
Private Support	--	--	92.5	*52.2*	92.5	*52.2*	--	--	--	--	185.0	*19.0*
TOTAL	362.3	--	874.5	*61.9*	335.1	*61.5*	694.7	*70.1*	129.4	*15.4*	2,396.0	*64.3*
Cost/man-year	35.0	*3.5*	36.3	*3.6*	36.3	*3.6*	65.0	*6.5*	33.0	*3.3*	41.1	*2,580.*
R&D MAN-YEARS	10,350.	*1,035.*	24,090.	*2,940.*	9,230.	*1,924.*	10,687.	*1,518.*	3,920.	*604.*	58,277.	*3,350.*

Source: Appendix F.
NOTE: Not all totals add exactly due to round-off approximations.

A major difference between the sectors is that over 40 percent of the R&D in education and health is performed in colleges and universities, while only 21 percent of the total in agriculture is performed in universities (see Table 7). In effect the portion in agriculture may be even lower since the bulk of university-performed R&D is conducted in the 53 State Agricultural Experiment Stations. These R&D centers are collocated and allied with universities, but are organizationally distinct from university departments. They receive over half of their support from the states and industry, and have research, development, and innovation responsibilities for their section of the country. Both faculty and SAES personnel commonly have joint appointments in the two organizations.

Table 7

R&D PERFORMANCE, FY 1968[1]
(man-years)

Sector	Universities & Colleges		Federal Government		Industry		All Other		Total
Education	2,121	45%	85	2%	116	2%	2,343	50%	4,665
Health	24,090	41%	10,350	18%	10,687	18%	13,150	23%	58,570
Agriculture	4,320	21%	5,400	21%	15,900	61%	--	--	25,620

[1]Tables 4, 5, 6.

As shown in Table 7, education and health are unlike agriculture in that little of the R&D is performed in industry. Industry performs 61 percent of the R&D effort in agriculture, 18 percent in health, and very little in education. The industrial R&D in health is concentrated in the drug industry (over 90 percent of the total[1]); whereas industrial R&D in agriculture occurs across the entire spectrum of production.

Table 7 shows that in FY 1968 very little education research was performed in Federal agencies (most of it data analysis), in contradistinction to health and agriculture where at least 15 percent of the research is intramural. In the health field most of the intramural work done by HEW is performed in the Washington, D.C., area, while only

[1]Conversation with analyst: Office of Resource Analysis, NIH.

a small fraction of the intramural agricultural R&D is performed in the Washington area (roughly 10 percent).

The performer charts also show that fewer levels of government are significant producers of R&D activity in the health and agriculture sectors in comparison to education, reflecting the fact that government is a major producer of education services.

The level of educational R&D performed nationally has increased by 50 percent and the amount performed has doubled since FY 1965 (see Table 5b) due to support from ESEA. Compared to the number of elementary and secondary school districts (20,000 in FY 1968), however, the level is even less than depicted in Table 5a, since much of the education research effort attributed to local school and state agencies is in the domain of data collection and "social bookkeeping" (Clark and Hopkins, 1969; p. 72).

COMPARISON BY RESEARCH ACTIVITY

Due to deficiencies in available data, only the agriculture and education sectors can be compared by research activity. Tables 4 and 5a show that in education more effort is spent on development (2630) than on research (2037), while in agriculture, the split is roughly equal between research (12,400) and development (13,220). The bulk of the development (60 percent) in agriculture is performed by the agricultural industry, but they support about two-thirds of the research, too.

Comparing entries in Tables 5a and 5b, the emphasis on development in education is a consequence of ESEA, primarily due to the introduction of the Regional Education Laboratories and development projects in the universities and local schools.

A major difference between the sectors is the small innovation effort in education (1,300 man-years) compared to a much larger one in agriculture (15,000 man-years). Even on a percentage basis, more effort is applied to innovation in agriculture, since almost 40 percent of total RD&I activity is allotted to innovation activities in agriculture, but only 20 percent in education. These figures are not complete, however, since not all activities which have innovation effects have been included in each sector.

The small size of the innovation effort in education is indicated by the comparison that the 15,000 man-years of effort in agriculture were applied to a community of 3,000,000 farms (an average of 1.2 man-days per year per farm), while 1.3 man-years of effort in education were applied to a community of 2,400,000 elementary and secondary teachers and administrators[1] (an average of 0.1 days per year per position). It should be realized, however, that there are many differences in the way this innovation effort is applied. For example, 30 percent of the formal innovation man-hours in FY 1968 and 50 percent in FY 1965 stem from NSF efforts to upgrade science teaching in the secondary schools through teacher retraining programs which encouraged the adoption of new science curricula. In these programs a number of teachers plus an education professional were brought together for a period of time, giving great leverage to the professional's time. Group activities are conducted in agriculture also, but a large share of the innovation effort is providing individual consultation service to farmers. Thus, the man-years of innovation effort are not strictly comparable in education and agriculture, but the order of magnitude difference in scale indicates a much greater effort to link R&D with practice in agriculture than in education. With roughly the same number of teachers as farmers there is more than ten times as much effort applied at the local level (11,000 man-years) in agriculture as in all of education (1,300 man-years).

EXPENDITURE OF R&D FUNDS BY PERFORMERS

The distribution of performers among R&D institutions in the economy as a whole can be compared to the distributions in agriculture, education, and health by examining performance (in dollars consumed) by institutional setting. As Table 8 shows, the education sector is distinct from the total national R&D effort in the high percentage of R&D done at universities and the low percentage done intramurally (by the Federal government) and by industry.

[1] *Saturday Review of Literature*, Sept. 19, 1970, p. 67. Inclusion of college and university teachers and administrators would add over 900,000 more positions.

Table 8

EXPENDITURE OF R&D FUNDS BY PERFORMER, FY 1968
(millions of dollars)

Sector	Universities & Colleges		Federal Government		Industry		All Other		Total
Education[1]	113	60%	2	1%	8[5]	4%	65	35%	188
Health[2]	874	36%	362	15%	695	29%	465	19%	2,396
Agriculture[3]	173	22%	159	20%	460	58%	--	0%	792
All Sectors[4]	3,400	12%	3,650	13%	19,250	70%	1,085	5%	27,380

[1]U.S. Office of Education, 1969, p. 91; increase Federal agencies (except USOE, NSF) and foundations by 20% (see Note b, Table D-1).
[2]Table 6.
[3]U.S. Department of Agriculture, 1969; and Appendix E.
[4]National Science Foundation (NSF 69-30) 1969.
[5]Appendix D, Table D-1.

The correlation between percentage of R&D man-hours in an institutional setting (Table 7) with the percentage of R&D dollars consumed in an institutional setting (Table 8) is very high for the health and agriculture sectors, but somewhat lower for education (45 percent of the education man-hours are performed in universities, but 60 percent of the dollars are consumed. This discrepancy could be caused by (1) the necessity due to data limitations of including some education innovation money in Table 8 (much of which goes to the universities), and (2) better pay in universities than in most other settings where educational R&D is performed. Neither of these factors could be investigated further.

IV. COMPARISON OF SPONSOR COMMUNITIES

COMPARISON BY INSTITUTIONS

The levels of sponsorship by institution and research activity are shown in Tables 9, 10, and 11.

The most striking result is that the Federal government supplied over 87 percent of the funds for education R&D in FY 1968 (see Table 12). The federal share was not as large (64 percent) in health, and even smaller (27 percent) in agriculture. The Federal share of support for all R&D sectors is slightly less than in health (55 percent).

State governments support R&D to a great extent in agriculture, but minimally in education and health. Based on a survey of all the states,[1] it has been estimated that State Departments of Education spent approximately $1.5 million on research and development in 1965. With the advent of ESEA Title V in 1966, it is unlikely that state support for R&D had increased by much in FY 1968.[2] Thus, support in FY 1968 was probably in the neighborhood of $2.0 million. The situation is much different in agriculture where the states have historically provided a large share of the funds (50 percent in FY 1968) for R&D performed in the State Agricultural Stations. In the health field, Table 12 shows that state government supplies a relatively small percent of the R&D funds, although that represents many more dollars than in education.

The industrial contribution to R&D correlates with the size of industry in the sector. Agricultural industry, which is the largest, spends the most on R&D, while a lesser amount is spent by the smaller pharmaceuticals industry. Education which has a negligible industrial component receives negligible R&D funds from industry.[3] There is no

[1] Phillips, 1967; Table XVIII.

[2] It is assumed that the availability of Title V funds at the Federal level for RD&I in State Departments of Education is more likely to replace state support of RD&I than to encourage it.

[3] According to U.S. Office of Education, 1969, p. 65, "The role of private industry in educational research and development has proven very difficult to ascertain." These authors decided not to estimate sponsorship by private industry, and no other precise figure could be found. The estimate quoted for industrial R&D in Table 11 is discussed in App. F.

Table 9

SPONSORS OF AGRICULTURE R&D, FY 1968
(dollars expended in millions)

RESEARCH ACTIVITY	SPONSOR BY INSTITUTION								TOTAL	
	USDA		State & County Government		Industry		Other Univ. & Federal Agencies		Except Column 4	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Basic research & Mission-oriented research	98	*18*	51	*13*	230	*69*	176	*53*	379	*73*
Operational research, product development, testing & education	112	*18*	71	*13*	230	*69*	176	*53*	413	*73*
Subtotal	210	--	122	--	460	*45*	352	*34*	792	*45*
Innovation	94	--	148	--	--	--	--	--	241	--
TOTAL	303	--	269	--	460	*45*	352	*34*	1033	*45*

Source: Appendix E and U.S. Dept. of Agriculture, 1966; pp. 54, 201.
NOTE: Not all totals add exactly due to round-off approximations.

Table 10

SPONSORS OF EDUCATION R&D, FY 1968
(in millions of dollars)

RESEARCH ACTIVITY	SPONSOR BY INSTITUTION														TOTALS	
	USOE		NSF		OEO		Other Federal Agencies		State Govern-ment		Private Firms		Founda-tions & Others			
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Basic research & mission-oriented research	42.8	*3.5*	--	--	4.7	*2.1*	30.9	*11.4*	1.0	*1.4*	3.0	*3.4*	10.6	*7.6*	93.0	*14.8*
Operational re-search, product development, testing & education	45.1	*4.1*	16.2	*1.5*	3.4	*2.2*	7.0	*2.8*	1.0	*1.2*	3.8	*4.0*	2.9	*2.2*	79.3	*7.4*
Subtotal	87.9	*5.4*	16.2	*1.5*	8.1	*3.0*	38.0	*11.8*	2.0	*1.9*	6.8	*5.3*	13.6	*8.0*	172.4	*16.6*
Innovation	16.2	*3.1*	41.6	*1.5*	4.7	*2.1*	1.1	*.7*	1.0	*1.2*	.8	*1.1*	.4	*.5*	65.8	*4.4*
TOTAL	104.1	*1.4*	57.8	--	12.8	--	39.1	*5.2*	3.0	*1.7*	7.5	*2.7*	14.0	*3.2*	238.3	*19.1*

Source: Appendix D.
NOTE: Not all totals add exactly due to round-off approximations.

Table 11

SPONSORS OF HEALTH R&D, FY 1965 & FY 1968
(in millions of dollars)

ACTIVITY	SPONSOR												TOTALS	
	NIH		Other HEW & Veterans Admin.		Other Federal Government		State & Local Government		Industry		Foundations & Institutional Fnds.			
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Basic research & mission-oriented research	605	130	139	30	268	23	35	20	234	72	167	25	1446	156
Operational research, product development, testing & education	259	130	171	30	85	23	35	20	381	78	18	19	949	158
TOTAL	864	--	310	--	353	--	69	7	616	61	185	19	2395	66

Source: Appendix F
NOTE: Not all totals add exactly due to round-off approximations.

Table 12

FEDERAL SHARE OF R&D SPONSORSHIP, FY 1968
(millions of dollars)

Sector	Federal Government	State & Local	All Other	Federal as % of Total	Govt. as % of Total
Education[1]	150	2	20	87	88
Health[2]	1,527	69	799	64	67
Agriculture[3]	210	122	460	27	42
All Sectors[4]	15,000	500	11,900	55	57

[1] Table 10.
[2] Table 11.
[3] Table 9.
[4] National Science Foundation (NSF 69-30), 1969, p. 14.

evidence in these figures that federal sponsorship stimulates or replaces industrial R&D activity.

Non-profit institutions and private individuals contribute a sizable ($185 million or 7 percent in FY 1968) portion of the funds for health R&D. The shares of sponsorship by non-profit sources in agriculture ($22 million or 2 percent in FY 1965) and in education ($7 million or 4 percent in FY 1968) are much smaller (U.S. Department of Agriculture, 1966, p. 54; U.S. Office of Education, 1969, p. 117).

Table 13

RATIO OF DEVELOPMENT TO RESEARCH SPONSORSHIP, BY 1968
(millions of dollars)

	Research Sponsorship	Development Sponsorship	Development / Research: Mean	Development / Research: Std.
Agriculture[1]	379	413	1.09	.28
Education[2]	93	79	.85	.15
Health[3]	2,446	949	.66	.13
All Sectors[4]	10,000	17,400	1.74	?

[1] Table 9.
[2] Table 10.
[3] Table 11.
[4] National Science Foundation (NSF 69-30), 1969, p. 14.

COMPARISON BY RESEARCH ACTIVITY

The agriculture, education, and health sectors are different from the economy as a whole in that a smaller proportion of R&D funds are spent on development (see Table 13). In the economy as a whole, development expenditures are 1.74 times research expenditures, while for agriculture, education, and health communities the ratio is close to or less than 1. As a caution, however, the level of uncertainty in the ratio for agriculture is high compared to the other sectors. As Tables 5a and 5b demonstrated, the relatively large ratio for education is a post-FY result, stemming from emphasis on development in ESEA.

THE COST OF R&D EFFORT

The cost of R&D effort in the various research activities can be measured by finding the ratio of sponsorship to performance (see Table 14). For agricultural research and development, the ratio is in the neighborhood of $31,000/man-year. For health, it is somewhat higher at $41,000/man-year, reflecting possibly greater use of technicians and equipment, and competition from medical doctors' salaries.

Table 14

COSTS OF R&D EFFORT, FY 1968

SECTOR Activity	Sponsorship[1] ($ millions)	Man-Years Purchased[2] (thousands)	Ratio $/Man-Year
Agriculture			
Research	379	12.4	30,600
Development	413	13.2	31,300
Innovation	241	15.0	16,100
Education			
Research	93	2.0	46,500
Development	79	2.6	30,300
Innovation	66	1.3	50,700
Health	2395	58.3	41,100
All Industry[3]			46,000

[1]Tables 8, 9, and 10.

[2]Tables 4, 5, and 6.

[3]Cost per scientist and engineer quoted in National Science Foundation, 1970. R&D in industry generally costs more than in universities and government.

In education, development costs about $30,000/man-year, but research is more expensive at $46,500/man-year. This figure is probably higher than the actual number.

The most likely source of this discrepancy is underestimation of individual producers in the university setting. Comparison of Tables B-1 and B-2 shows that with few exceptions, over 90 percent of the R&D in the university setting in FY 1968 was supported by USOE or NSF programs, an unexpectedly high number. This fraction would decrease if the data for individual producers in FY 1968 (Table B-1) in the university setting were increased. These data were obtained by inflating Clark and Hopkins estimates of the number of individual performers in FY 1965 by the growth in Federal programs. If Clark and Hopkins estimates of university performers in FY 1965 are low then the estimate of performance in the university setting in FY 1968 would also be too low.

The estimates of university performers in FY 1965 (by Clark and Hopkins, 1968) were based on a survey of the total population of education R&D performers, but especially in non-school of education settings; only a small correction for non-respondence was made. Actual activity was estimated to be less than two times larger than the number of returned questionnaires. If Clark and Hopkins had tripled or quadrupled (tantamount to a 33 percent or 25 percent sample return) their estimates for the individual producers in the non-school of education/university setting, the cost per man-year ratio for research would have turned out to be $35,000, and the ratio for development would not have changed very much.

The ratio for research can also be reduced to $35,000 without changing the ratio for development by dropping NIMH and NIH from the list of sponsors. This is further evidence that individual performers in non-school of education settings have been undercounted, since many NIMH and NIH grants go to these performers.

Even so, the per man-year costs of research and development are the same order of magnitude, and very close to the costs in other sectors. Since the figures for education performance and sponsorship are based on independent sources of data, the close agreement gives confidence that no large block of education R&D activity has been seriously underestimated on either the performer's or the sponsor's side.

THE COST OF INNOVATION EFFORT

According to Table 14, the innovation effort in education is substantially more expensive per man-year in education ($50,000) than in agriculture ($16,000). Innovation is more expensive in education because NSF's teacher retraining programs are a substantial part of the education format. NSF's procedure is to bring teachers together from all across the country for workshops, making it necessary to pay travel and subsistence expenditures. The format is less expensive in agriculture, since it involves extension agents working with farmers on their own farms. The differential, however, is not as high as it appears in Table 14, since the cost of office space supplied by universities and government is not included in the agriculture sector. Even the approximate magnitude of this overhead cost is not readily available from government or other sources.

SCALE OF SECTOR ACTIVITY

The absolute levels of R&D sponsorship are not immediately comparable without establishing a measure of the scale of production activity. A natural measure to use is the contribution to GNP produced in each sector. R&D activity can then be compared by specifying its size as a percentage of value added in a sector. Table 15 shows the contribution to GNP for the agriculture, education, and health sectors in FY 1965 and FY 1968.

As a percentage of sector product, education R&D has remained near 3 percent in the years FY 1965 and FY 1968. At the same time, expenditures for health-related R&D decreased from 5 percent of sector product to 4.7 percent. The agriculture expenditures for R&D were 1.1 percent of the sector product in FY 1968 and 1.2 percent in FY 1965.

In the economy as a whole, about 3 percent of the GNP is invested in research and development activities. These figures are displayed in Table 16.

HISTORY OF R&D SPONSORSHIP BY PRIMARY AGENCIES

The cross-section views of R&D activity in FY 1965 and FY 1968 do not capture the dynamics of investment in R&D, since several years are

Table 15

SECTORAL CONTRIBUTION TO GNP
($ billions)

Sector	CY 1965	CY 1968
Agriculture		
Gross Farm Product[1]	23.70	24.90
Food and Kindred Products Manufacture[2]	21.00	23.10
Tobacco Manufacture[2]	3.30	3.60
Lumber and Wood Product Manufacture[2]	4.80	5.70
Paper and Allied Products Manufacture[2]	7.10	8.70
Textiles Manufacture[2]	6.10	7.50
	66.00	73.50
Education		
Private Consumption[3]	5.59	8.40
Purchases of Structures[4]	.75	.98
Government Purchases, Goods and Services[5]		
Federal	.42	.78
State and Local	29.82	42.86
	35.58	53.02
Health		
Private Consumption[6]	28.08	38.58
Purchases of Structures[7]	1.40	1.57
Government Purchases, Goods and Services[8]		
Federal	2.07	2.55
State and Local	5.87	8.76
	37.42	51.46

All references, U.S. Office of Business Economics, 1969.

1. Table 1.17.
2. Unpublished figure for value added; William Eisenberg, Office of Business Economics, U.S. Department of Commerce.
3. Table 2.5, Item X.
4. Table 5.2, Private, Educational New Construction.
5. Table 3.10, Government Purchases, Goods and Services.
6. Table 2.5, Medical Expenses.
7. Table 5.2, Private Structures, Hospital and Institutional.
8. Table 3.10, Lines 21, 37.

Table 16

R&D SPONSORSHIP AS A FRACTION OF GNP

Sector	R&D Sponsorship ($ millions)		Sector Product ($ billions)		Ratio (percent)	
	FY 1965	FY 1968[5]	FY 1965	FY 1968	FY 1965	FY 1968
Agriculture	791[1]	792	66.00	73.50	1.20	1.10
Education	100[2]	172	35.58	53.02	.28	.32
Health	1,840[3]	2,395	37.42	51.46	5.00	4.70
All Sectors	20,500[4]	25,330	684.80	865.70	3.00	2.90

[1]U.S. Department of Agriculture, 1966; p. 52.

[2]U.S. Office of Education, 1969; pp. 128, 129, 116.

[3]U.S. House of Representatives, 1971; p. 43.

[4]National Science Foundation (NSF 69-30), 1969.

[5]Tables 9, 10, and 11.

thought to be required for R&D results to diffuse into practice. To better represent these dynamics, the level of R&D expenditures can be examined over a number of previous years.

The historical trends of R&D activity supported by the primary government agencies in agriculture, education, and health are displayed in Fig. 1a. No time series data for other sponsors were found. The same data plotted in Fig. 1a are replotted in Fig. 1b after normalizing them to the level of sponsorship in FY 1964, and deflating the result by 6 percent per year to account for increasing cost of a research man-year (U. S. Office of Resource Analysis, 1969, p. 36).

Figure 1b shows that the National Institutes of Health have increased their sponsorship of R&D dramatically in recent years, while agriculture has supported research at about the same level for a long time. The Office of Education is a newcomer to the R&D field, having provided significant support starting only in 1962. National Science Foundation's education effort started somewhat earlier, in the late 50s. While no data are available, there is no reason to suspect that non-Federal government sponsorship of education R&D has increased significantly in the last ten years. Since the Federal government now provides over 80 percent of the funds for education R&D, the total money provided for education R&D prior to the 1960s was, therefore, probably very small. If, as some have argued, 10 to 20 years are required to transform knowledge into products, then the great payoffs for the recent increases in health and education research are yet to come. In contrast, agriculture has received generous support for R&D for many years, and, as might be expected, manifests a lively pace of innovation and change.

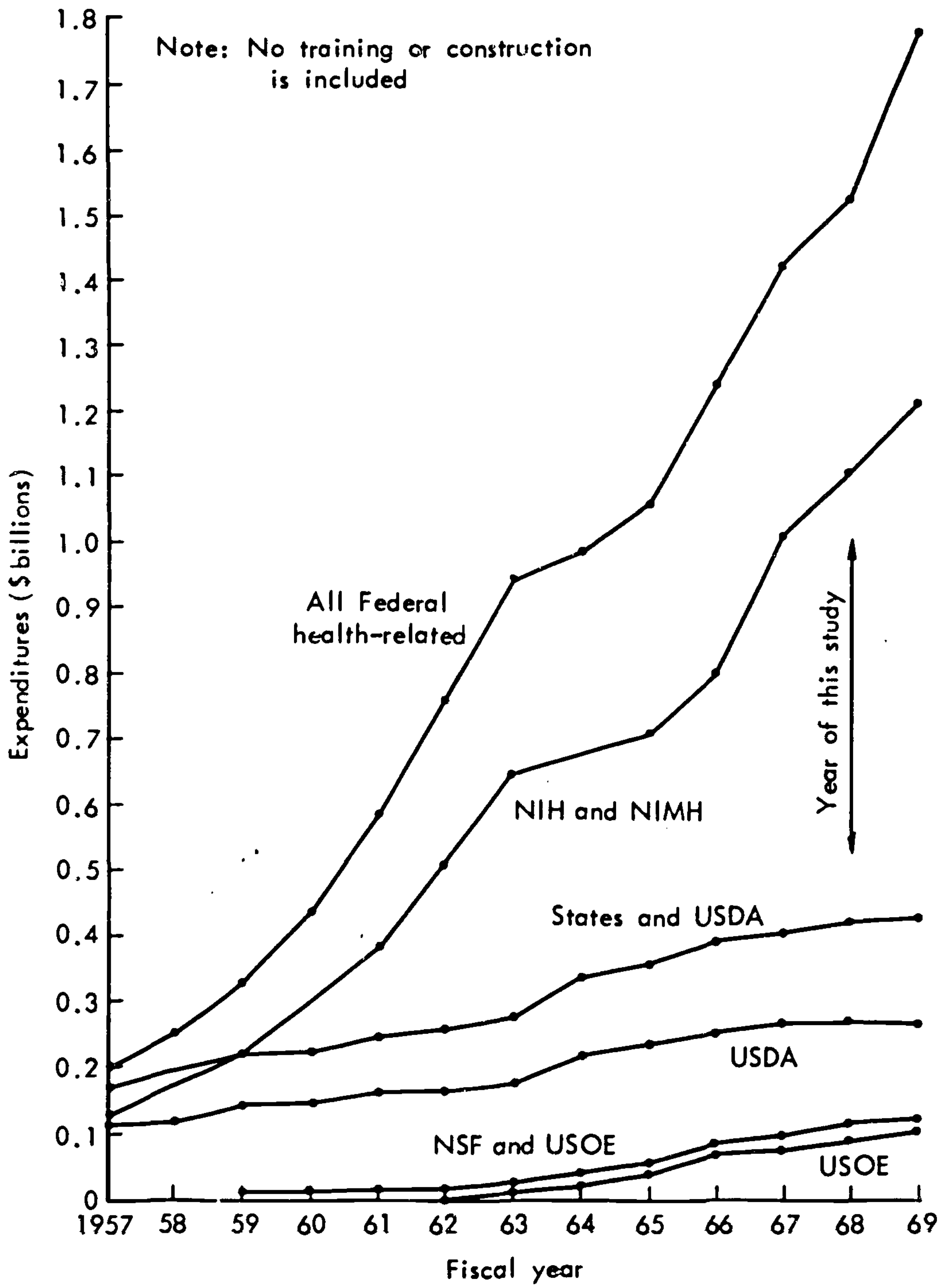

Fig. 1a—Sponsorship of research and development by primary agencies in the agriculture, education, and health sectors

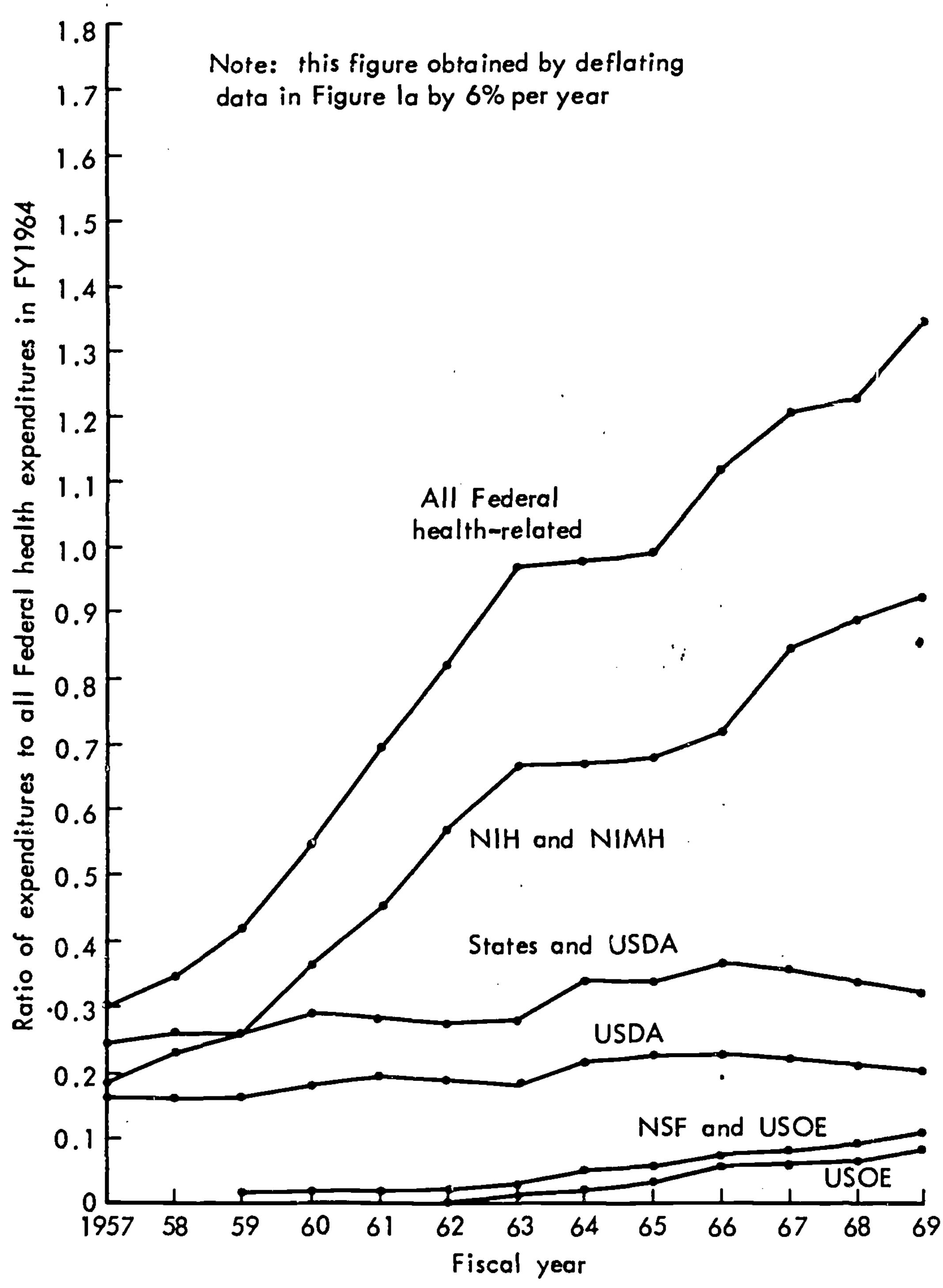

Fig. 1b—Sponsorship of research and development by primary agencies in agriculture, education, and health sectors

V. ADDITIONAL COMMENTARY ON THE RESULTS OBTAINED

Against the often heard statement that "development is much more 'expensive' than 'research'" is the fact that even in the sectors without significant industry, roughly as much is spent for research as is spent for development. Individual research projects are generally smaller than development projects and thus cost less, but apparently many more are supported. If it is assumed that the balance between intrasectoral R&D shown in Tables 4 through 6, and 9 through 11 is optimal, then it follows that the expected marginal payoff from research in each sector equals the expected marginal payoff from development. Since roughly the same input of dollars is spent on each mode of activity, it would just as well be said that research is as "expensive" as development. This string of argument only points out the fallacy of stating that development is more expensive than research. The important issue is not expense, but that the total budget in a sector is divided to equalize the marginal payoff for research, for development, and for innovation. This prescription is more of conceptual than practical use, however, since this optimal level cannot be determined analytically.

The marginal payoff from RD&I should also be equalized between sectors so that the last dollar spent on RD&I should be expected to return as much in education as in health or agriculture, but again this prescription is not useful because a means of calculating these marginal payoffs is not available. Thus, even though this study shows that education RD&I expenditures are very low in comparison to agriculture and health expenditures, the evidence given does not mandate more or less support for education RD&I.

Nevertheless, it is difficult to ignore entirely the proposition that support for education R&D is too low; that increased expenditure on R&D would not more than pay for itself in increased educational effectiveness. In the industrial sectors, there is scientific evidence that expenditures on R&D produce significant increases in productivity. One study estimates that a 1 percent increase in R&D generates from a .1 to a .7 percent increase in productivity (Mansfield, 1968). Another study in the chemical and drug industries has estimated that the rate of growth of productivity is much more a consequence of investment in R&D than capital equipment (Minasian, 1962). Especially in a labor-intensive industry such as education, it is reasonable, though not provable, to expect that investment in R&D will enable more to be done per unit of labor input.

Rather than attempting to calculate the marginal payoffs of educational RD&I or estimate increases in productivity, it seems more fruitful to search for imperfections in the way money is allocated to education which result in a suboptimal share of resources. There is a variety of imperfections which can be postulated. One is that the record of educational R&D is poorly known; that is, more has been achieved than is realized by those who set budget levels. The argument is that if the results were better known, more support would be forthcoming. Another is that educational R&D suffers from a critical mass effect; that increases in support could substantially increase the marginal payoffs in education R&D.

Perhaps a more plausible imperfection is that an alternative approach to managing the conduct of education R&D might significantly improve the payoff gained for money spent. The traditional, piecemeal approach to R&D may work in other fields such as health or agriculture, where a component of the system can be examined in the isolation of a laboratory, but it may not work as well in education where a component of the system cannot be extracted so easily. If so, a programmatic approach[1] which grapples with at least chunks of the system at once and features large-scale experiments and careful research designs may provide substantially larger returns than those gained from equal expenditures on piecemeal projects. Borrowing economic terms, this argument amounts to asserting that the "production frontier" for education R&D can be shifted outward by managing the expenditure of funds in a

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[1]Programmatic research and development can be characterized as a sustained, "multi-issued," interdisciplinary approach to solving complex problems. It is a managed interplay among a diagnostic phase of sorting out symptoms and causes, a knowledge-building phase of researching critical questions, and a design phase of testing the results for correctness. Programmatic research and development is not a technique like PERT-charting or cost-benefit analysis, but a strategy for solving problems.

different way. Because of differences in the nature of the subject being researched, the same argument may not hold for health and agriculture.

Other imperfections may be found in understanding why a government policy to fund the building of a knowledge base does not necessarily trigger a non-government effort to exploit that knowledge. As Table 12 shows, 88 percent of the education and 67 percent of the health R&D dollars come from government, while only 42 percent of the agriculture R&D dollars come from government. Yet, as Tables 9, 10, and 11 show, non-government-sponsored development effort accounts for 29 percent of the total dollars for R&D in the agriculture sector, 17 percent in health, and only 4 percent in education. Assuming that government research merits utilization, apparently there are circumstances where development effort must be stimulated along with research for research to be transformed into developed products. Government can do this by selecting patent policies, fostering demand for innovative products and ideas, or undertaking the job of development itself. Analysis of the reasons why non-governmental support for development and innovation does not always occur, should suggest the most workable remedies.

Appendix A

PERFORMERS OF EDUCATION RD&I, FY 1965

Quotations for man-years of education R&D by institutional setting and research function in FY 1965 were developed by transforming data from Clark and Hopkins' manpower study (Source C, Table 9, which is reproduced as Table A-1 here) into the format laid down in Chapter 2.0. The transformations needed for this conversion are developed in this appendix. The language of probability theory will be used to describe the construction of these transformations. Besides its explicitness, using probability theory has two benefits:

(1) It emphasizes that both hard data and subjective knowledge are incorporated in the resulting estimates, and

(2) It provides a means for making quantitative statements about the degree of uncertainty in the resulting estimates.

To begin, two families of random variables are assigned:

P_{65} = total number of positions held in FY 1965, and

A_{65} = total man-years of effort in FY 1965.

Individual members of these families are identified by specifying three parameters which isolate a particular *work group* that the random variables describe. These parameters are:

I = Institutional setting (a list of settings appears in Table A-1),

J = Job role (list of titles appears in Table A-1), and

R = Activity class (a list of activities appears in Table A-2).

With these definitions, the random variable $P_{65}(I,J,R)$ is the number of positions held in work group (I,J,R) in FY 1965, and $A_{65}(I,J,R)$ is the man-years of effort in FY 1965 in work group (I,J,R).

Following the theory of subjective probability developed by Savage, a person's a priori state of information about the true value of an uncertain quantity can be described by specifying a probability distribution over the uncertain quantity. The person translates his knowledge into a probability distribution by comparing standard or normal

Table A-1

$P_{65}(I,J)$--RD&I POSITIONS BY INSTITUTIONAL SETTING AND JOB ROLE, FY 1965
JOB ROLE J

Institutional Setting, I	RD&I Program Directors and Staff[1]		Individual RD&I Personnel[1]: Hard-core Producers		Individual RD&I Personnel[1]: Regular Producers		Individual RD&I Personnel[1]: Occasional Producers		NSF Supported Teacher Institute Program[2]		Sub-Totals	
	Mean*	Std.+	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Colleges & Universities	--	--	--	--	--	--	--	--	375	56		
Schools & Colleges of Education	269	65	115	36	265	78	620	90	--	--		
Schools & Departments of Psychology[3]	110	30	69	24	225	58	351	89	--	--		
Other Behavioral and Social Science Depts.[4]	75	15	120	44	212	68	278	88	--	--		
Other Discipline and Academic Areas[4]	262	124	56	28	104	33	178	50	--	--		
College and University Administration Areas	151	43	~0	--	7	1	48	4	--	--		
U.S. Office of Education	35	7	31	5	46	7	23	3	--	--		
State Depts. of Educ. & Other State Agencies	255	92	25	11	25	7	65	15	--	--		
Schools & School Systems	275	59	10	4	120	57	140	43	--	--		
Private Research Institutes & Agencies	303	100	--	--	--	--	--	--	--	--		
Professional Education Assns.	90	20	--	--	--	--	--	--	--	--		
Other Professional, Public, & Lay Associations	278	113	--	--	--	--	--	--	--	--		
Interagency Organizations	54	13	--	--	--	--	--	--	--	--		
Business & Industrial Organizations	152	50	--	--	--	--	--	--	--	--		

*Mean = $E[P_{65}(I,J)]$.

+Std. = Standard deviation of $P_{65}(I,J)$.

[1]Clark and Hopkins, 1968; Tables 8, 9, and 56. Let the mean of $P_{65}(I,J)$ be the values in Table 9. To the program directors and staff category, add project directors and staff (Table 8), and NSF-CCI positions (Table 56). NSF-CCI positions are added because none were included in Table 9 (see Source C, p. 100). Let the standard deviation be one-half the estimated mean minus the documented minimum for program directors and staff (Table 8).

[2]Appendix C.

[3]Increase "Individual..." category by 50 percent over values in Table 9, Source C. The authors of Source C gave very little compensation for undercounting in this category.

[4]Increase "Individual..." category by 200 percent.

lotteries against lotteries on the uncertain quantity in the following way. Suppose the author is offered a choice between two lotteries. One lottery is a "coin" which turns up a head with probability p and a tail with probability 1-p. The payoff for a head is W, and for a tail is L. The other lottery pays off W if the random variable in question is greater than K_o, and pays off L if the random variable is less than K_o. For concreteness, assume that this random variable is $P_{65}(I,J,R)$. The author selects a value of $p = p'$ where $0 \leq p' \leq 1$, such that he feels indifferent between the two lotteries offered. The selected value p' is then defined as equal to the subjective probability, $\Pr\{P_{65}(I,J,R) \leq K_o\}$. By repeating this indifference test for other values of K_o, the author's a priori state of knowledge about $P_{65}(I,R,J)$ is specified. A more detailed explanation of the subjective probability concept can be found in Raiffa, 1968, or Savage, 1954.

Additional knowledge about the true value of $P_{65}(I,J,K)$ will "narrow" the author's subjective probability distribution for $P_{65}(I,J,R)$, by reducing the range of values over which the true value of $P_{65}(I,J,R)$ will be thought to lie. This is the important feature of the subjective probability concept which will be used to quantify uncertainties in the performance and sponsorship tables in this report.

A.1 MODEL FOR TRANSFORMING EDUCATION RD&I PERFORMER DATA

Each position in a work group (I,J) generates no more than a man-year of RD&I activity; thus, positions in work group (I,J) are related to man-years of activity by a constant value of less than one;

$$A_{65}(I,J) = \beta_{65}(I,J)P_{65}(I,J) \qquad \text{(A-1)}$$

The units of $\beta_{65}(I,J)$ are obviously total man-years divided by total positions.

Since only a fraction of the total activity in work group (I,J) is devoted to activity class R; $A_{65}(I,J,R)$ is related to $A_{65}(I,J)$ by[1]

$$A_{65}(I,J,R) = \alpha_{65}(I,J,R)A_{65}(I,J). \qquad \text{(A-2)}$$

The fraction $\alpha_{65}(I,J,R)$ is a random variable since only partial data on its value are available. Since $\sum_R A_{65}(I,J,R) = A_{65}(I,J)$, necessarily;

$$\sum_R \alpha_{65}(I,J,R) = 1. \qquad \text{(A-3)}$$

From Equation A-2 it is clear that the α_{65}'s are unitless quantities.

Substituting Eq. A-1 into Eq. A-2, and summing over all job roles gives the man-years of activity in work group (I,R), a quantity desired to describe education R&D performance.

$$A_{65}(I,R) = \sum_J \alpha_{65}(I,J,R)\beta_{65}(I,J)P_{65}(I,J). \qquad \text{(A-4)}$$

Data are available for all the quantities on the right-hand side of Eq. A-4, and so it will serve as the basic equation for transforming education data into man-years of performance. Before proceeding, however, a further assumption needs to be made.

This assumption is that given a work group (I,J,R), the random variables $\alpha_{65}(I,J,R)$, $\beta_{65}(I,J)$, and $P_{65}(I,J,R)$ are independent.

<u>Assumption 1</u>. For any work group (I,J,R), the random variables $\alpha_{65}(I,J,R)$, $\beta_{65}(I,J)$, and $P_{65}(I,J)$ are independent.

This assumption holds if and only if being told the exact value of one of these variables does not change the author's state of information about any other of the random variables. For example, if being told

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[1] In the data sources a position was added to an activity class R, if more time was spent on activity R than any other activity. Thus α_{65} is the fraction of positions in a research class and does not divide a person's time into the activity classes.

the exact value of $P_{65}(I,J)$ made the analyst change his subjective distribution for $\beta_{65}(I,J)$, then Assumption 1 would not hold.

A.2. EXPECTED VALUE OF EDUCATION RD&I PERFORMANCE

Display of the probability distribution for $A_{65}(I,R)$ in every work group is clearly impractical. Instead the expected value of $A_{65}(I,R)$ will be arbitrarily adopted as a suitable estimate of the true value of $A_{65}(I,R)$. Taking the expected value of Eq. A-4, and invoking the independence assumption (Assumption 1) gives the model used to transform the data in Table A-1 to the desired result in Table A-2.

$$E[_{65}(I,R)] = \sum_J E[\alpha_{65}(I,J,R)]\ E[\beta_{65}(I,J)]\ E[P_{65}(I,J)]. \qquad \text{(A-5)}$$

Setting $E[\alpha_{65}(I,J,R)] = \bar{\alpha}_{65}(I,J,R)$ and $E[\bar{\beta}_{65}(I,J)] = \bar{\beta}_{65}(I,J)$--an abbreviation that will be used throughout these appendices--Eq. A-5 becomes:

$$E[A_{65}(I,R)] = \sum_J \alpha_{65}(I,J,R)\ \beta_{65}(I,J)]E[P_{65}(I,J)]. \qquad \text{(A-6)}$$

The subjective estimates $\bar{\alpha}_{65}$ and $\bar{\beta}_{65}$ used in calculating Table A-2 are developed in Table A-3 and A-4. The annotations below these tables indicate the sources of data, and the specific assumptions used in estimating the $\bar{\alpha}_{65}$'s and the $\bar{\beta}_{65}$'s.

In general the procedure used to estimate all input quantities (the $\bar{\alpha}_{65}$'s, $\bar{\beta}_{65}$'s and $E[P_{65}(I,J)]$'s) was as follows. By integrating, it can be shown that for the Beta, Gamma, and Normal probability distributions, approximately ".35 of the probability" lies between plus and minus one-half standard deviation of the mean, and approximately ".90 of the probability" lies between plus and minus two standard deviations of the mean. Since these three families of distributions are robust enough to adequately describe a state of information for any of the input quantities to be estimated, this interpretation applies for all these quantities. Thus, the procedure for estimating each input quantity is to match a choice of mean value and standard

Table A-2

$A_{65}(I,R)$--MAN-YEARS OF RESEARCH ACTIVITY BY INSTITUTIONAL SETTING, FY 1965

Setting, I	Research Activity, R: Basic and Mission-Oriented Research (R=1) Mean*	Std+	Development Activities (R=2) Mean	Std	Innovation Activities (R=3) Mean	Std	Subtotals Mean	S.d
Colleges and Universities	1321	177	552	147	616[1]	110	2492.7	(214)
Schools and Colleges of Education	(582)	(148)	(155)	(84)	(102)	(67)	(841)	(137)
Schools and Departments of Psychology	(258)	(60)	(66)	(36)	(42)	(28)	(367)	(56)
Other Behavioral and Social Science Depts	(270)	(59)	(48.3)	(33)	(37)	(18)	(355)	(61)
Other Discipline and Academic Areas	(132)	(35)	(219.26)	(105)	(44)	(42)	(396)	(123)
College and University Administration Areas	(79)	(36)	(63.6)	(33)	(16)	(41)	(159)	(42)
U.S. Office of Education	76	10	9.0	5	5	3	90	10
State Departments of Education and Other State Agencies	157	122	59.5	57	77	80	294	89
Schools and School Systems	162	51	158.8	64	45	40	365	66
Private Research Institutes and Agencies	130	72	129.5	72	29	81	288	96
Professional Education Associations	28	30	28.2	22	28	22	86	20
Other Professional, Public, and Lay Associations	8	14	214.0	92	42	32	264	108
Interagency Organizations	17	17	16.9	13	17	13	51	126
Business and Industrial Organizations	39	19	76.5	36	29	17	144	48
	1938	236	1244	210	888	169	4074	286

*Mean = $E\left[A_{65}(I,R)\right]$.

+Std = Standard deviation of $A_{65}(I,R)$.

[1]Man-years in NSF teacher institutes are also included.

SOURCE: Equations A-5 and A-10; Tables A-3, A-4, and A-5.

Table A-3

β_{65}(I,J)--THE FRACTION OF A MAN-YEAR DEVOTED TO RESEARCH ACTIVITIES BY INSTITUTIONAL SETTING AND JOB ROLE, FY 1965

	Job Role, J									
	RD&I Program Directors and Staff[1] (J=1)		Individual RD&I Personnel[2]: Hard Core Producers (J=2)		Individual RD&I Personnel[2]: Regular Producers (J=3)		Individual RD&I Personnel[2]: Occasional Producers (J=4)		NSF Supported Teacher Institute Program[3] (J=5)	
Setting, I	Mean*	Std+	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Colleges and Universities									1.0	
Schools and Colleges of Education	.95	.05	.90	.05	.40	.05	.25	.05		
Schools and Departments of Psychology	.95	.05	.90	.05	.40	.05	.25	.05		
Other Behavioral and Social Science Depts	.95	.05	.90	.05	.50	.05	.25	.05		
Other Discipline and Academic Areas	.95	.05	.90	.05	.50	.05	.25	.05		
College and University Administration Areas	.95	.05	.90	.05	.50	.05	.25	.05		
U. S. Office of Education	.95	.05	.90	.05	.50	.05	.25	.05		
State Depts of Education and Other State Agencies	.95	.05	.90	.05	.50	.05	.25	.05		
Schools and School Systems	.95	.05	.90	.05	.50	.05	.25	.05		
Private Research Institutes and Agencies	.95	.05	.90	.05	.50	.05	.25	.05		
Professional Educational Associations	.95	.05	.90	.05	.50	.05	.25	.05		
Other Professional, Public, and Lay Associations	.95	.05	.90	.05	.50	.05	.25	.05		
Interagency Organizations	.95	.05	.90	.05	.50	.05	.25	.05		
Business and Industrial Organizations	.95	.05	.90	.05	.50	.05	.25	.05		

*Mean = $E\left[\beta_{65}(I,J)\right]$.

+Std = standard deviation $\beta_{65}(I,R)$.

[1] Clark and Hopkins, 1968, p. 25. Program directors and staff spend at least two-thirds time on education RD&I.

[2] Ibid. Hard-core producers spend at least two-thirds time on education RD&I. Regular producers spend between one-third and two-thirds time; occasional producers between one-fifth and one-third.

[3] Appendix C.

Table A-4

$\bar{a}_{65}(I,J,R)$--THE EXPECTED FRACTION OF TOTAL EFFORT IN EACH RESEARCH ACTIVITY, FY 1965

	Job Role, J				
	RD&I Program Directors and Staff (J=1)	Individual RD&I Personnel: Hard-Core Producers (J=2)	Individual RD&I Personnel: Regular Producers (J=3)	Individual RD&I Personnel: Occasional Producers (J=4)	NSF Supported Teacher Institute Program (J=5)
Setting, I	$\bar{a}_{65}(I,J,1)/\bar{a}_{65}(I,J,2)/\bar{a}_{65}(I,J,3)$				
Colleges and Universities					.00/.00/1.00
Schools and Colleges of Education[1]	.33/.33/.33	.85/.12/.03	.85/.12/.03	.85/.12/.03	
Schools and Departments of Psychology[2]	.33/.33/.33	.85/.12/.03	.85/.12/.03	.85/.12/.03	
Other Behavioral and Social Science Depts[3]	.40/.20/.40	.85/.12/.03	.85/.12/.03	.85/.12/.03	
Other Discipline and Academic Areas[4]	.03/.81/.16	.85/.12/.03	.85/.12/.03	.85/.12/.03	
College and University Administration Areas[5]	.50/.40/.10	.50/.40/.10	.50/.40/.10	.50/.40/.10	
U. S. Office of Education[6]	.85/.10/.05	.85/.10/.05	.85/.10/.05	.85/.10/.05	
State Depts of Education and Other State Agencies[7]	.47/.22/.31	.85/.12/.03	.85/.12/.03	.85/.12/.03	
Schools and School Systems[8]	.28/.56/.16	.85/.12/.03	.85/.12/.03	.85/.12/.03	
Private Research Institutes and Agencies[9]	.45/.45/.10				
Professional Education Associations[10]	.33/.33/.33				
Other Professional, Public and Lay Associations[11]	.03/.81/.16				
Interagency Organizations[12]	.33/.33/.33				
Business and Industrial Organizations[13]	.27/.53/.20				

Table A-5

$Std[a_{65}(I,J,R)]$--STANDARD DEVIATION OF $a_{65}(I,J,R)$, FY 1965

Setting, I	Job Role, J: RD&I Program Directors and Staff	Individual RD&I Personnel: Hard-Core Producers	Individual RD&I Personnel: Regular Producers	Individual RD&I Personnel: Occasional Producers	NSF Supported Teacher Institute Program
	$Std a_{65}(I,J,1)/Std a_{65}(I,J,2) Std_{65}(I,J,3)$				
Colleges and Universities					.00/.00/0.00
Schools and Colleges of Education[1]	.24/.24/.24	.12/.12/.05	.12/.12/.05	.12/.12/.05	
Schools and Departments of Psychology[2]	.24/.24/.24	.12/.12/.05	.12/.12/.05	.12/.12/.05	
Other Behavioral and Social Science Depts[3]	.24/.20/.24	.12/.12/.05	.12/.12/.05	.12/.12/.05	
Other Discipline and Academic Areas[4]	.07/.15/.14	.12/.12/.05	.12/.12/.05	.12/.12/.05	
College and University Administration Areas[5]	.15/.14/.09	.15/.14/.09	.15/.14/.09	.15/.14/.09	
U. S. Office of Education[6]	.11/.10/.07	.12/.12/.05	.12/.12/.05	.12/.12/.05	
State Depts of Education and Other State Agencies[7]	.15/.14/.14	.12/.12/.05	.12/.12/.05	.12/.12/.05	
Schools and School Systems[8]	.15/.16/.11	.12/.12/.05	.12/.12/.05	.12/.12/.05	
Private Research Institutes and Agencies[9]	.15/.15/.10				
Professional Education Associations[10]	.24/.24/.24				
Other Professional, Public, and Lay Associations[11]	.07/.15/.14				
Interagency Organizations[12]	.24/.24/.24				
Business and Industrial Organizations[13]	.10/.11/.10				

NOTES TO TABLES A-4 AND A-5

1. Of the 269 positions in "Program Directors...," 70 are in NSF-CCI programs, and 124 are in research and service bureaus. The former are development-oriented, and the latter research- and innovation-oriented. The assigned means reflect roughly an equal split between activity classes, with a high standard deviation for each value, reflecting the great uncertainty in these estimates. The estimates of α_{65} for "Individual RD&I Personnel" were assumed to distribute as regular research projects (Clark and Hopkins, 1968, p. 248).

2. Of the 110 positions in "Program Directors...," 26 are in NSF-CCI programs and at least 48 are in research and service bureaus. The same mean values and standard deviations as for Schools and Colleges of Education were assumed.

3. Of 75 positions in "Program Directors...," 45 are in research and service bureaus. The rest are in other programs. Consequently, it was assumed that a higher portion of the work was research and innovation, and a smaller portion was development. Almost complete ignorance of the exact values was assumed by assigning a high standard deviation for the research and development fractions. The estimates of α_{65} for "Individual RD&I Personnel" were assumed to distribute as individual research projects.

4. Most of the "Program Directors and Staff" are in NSF-CCI projects so the distribution for NSF-CCI projects was assigned for the mean values (Clark and Hopkins, 1968, p. 248). Again, individual personnel were assumed to distribute as individual research projects.

5. Clark and Hopkins, 1968, p. 85.

6. USOE personnel are primarily engaged in collection of statistics or policy research, both of which qualify as research activities. Thus, the bulk of activity was assumed to be research.

7. The mean fraction of "Program Directors and Staff" in each activity was distributed as State Research Division Personnel (Clark and Hopkins, 1968, p. 248). "Individual RD&I Personnel" were distributed as regular research projects.

8. The mean fraction of "Program Directors and Staff" in each activity was distributed as Title III Projects (Clark and Hopkins, 1968, p. 248). Individual projects were distributed as regular research projects, ibid.

9. Source C, pp. 98-99.

10. See Clark and Hopkins, 1968, pp. 98-99. The estimates assert complete ignorance of the fraction of work performed in each category.

11. The bulk of the work in this category is NSF-CCI sponsored, so activity was distributed as NSF-CCI projects (Clark and Hopkins, 1968, p. 248). A slight adjustment for the possibility of some research was made, however,

12. Complete ignorance of the activity class distribution was assumed.

13. A breakdown equivalent to regular development projects was assumed (Clark and Hopkins, 1968, p. 248). The performers included in this setting are described in Clark and Hopkins, 1968, p. 102.

deviation with the state of available information using the interpretation explicated at the beginning of this paragraph. The result of this procedure will be a set of quotations for which the true value of each quantity being estimated lies between plus and minus one-half standard deviation in 35 out of 100 (on the average) cases and between plus and minus two standard deviations of the mean in 90 out of 100 cases.

VARIANCE OF EDUCATION RD&I PERFORMANCE

Specifying just $E[A_{65}(I,R)]$ fails to convey that $A_{65}(I,R)$ is an uncertain quantity. This difficulty will be remedied by displaying the variance of $A_{65}(I,R)$ alongside $E[A_{65}(I,R)]$.

The variance is a reasonable choice, since $A_{65}(I,R)$ is the sum of several terms. Therefore, by the Central Limit Theorem, $A_{65}(I,R)$ will have (at least approximately) a Normal distribution. Since the Normal is a two-parameter distribution, specification of its expected value and variance fixes its mathematical form exactly. Knowing the mathematical form, the probability that the true value of $A_{65}(I,R)$ lies between selected bounds can be easily calculated for any selection of bounds.

To derive an expression for $Var[A_{65}(I,R)]$, make the following substitutions into Eq. A-4:

$$\alpha_{65}(I,J,R) = \bar{\alpha}_{65}(I,J,R) + \delta\alpha_{65}(I,J,R), \tag{A-7a}$$

$$\beta_{65}(I,J) = \bar{\beta}_{65}(I,J) + \delta\beta_{65}(I,J), \text{ and} \tag{A-7b}$$

$$P_{65}(I,J) = E[P_{65}(I,J)] + \delta P_{65}(I,J), \tag{A-7c}$$

where $\delta\alpha_{65}$, $\delta\beta_{65}$, and δP_{65} are small corrections added to the means of respectively α_{65}, β_{65}, and P_{65}. After substitution and rearrangement, of Assumption 2, Eq. A-4 becomes:

$$A_{65}(I,R) = \sum_J \bar{\alpha}_{65}(I,J,R)\,\bar{\beta}_{65}(I,J)\,E[P_{65}(I,J)]$$

$$+ \sum_J \delta\alpha_{65}(I,J,R)\,\bar{\beta}_{65}(I,J)\,E[P_{65}(I,J)]$$

$$+ \sum_J \bar{\alpha}_{65}(I,J,R)\ \delta\beta_{65}(I,J)\ E[P_{65}(I,J)]$$

$$+ \sum_J \bar{\alpha}_{65}(I,J,R)\ \bar{\beta}_{65}(I,J)\ \delta P_{65}(I,J) \qquad \text{(A-8)}$$

$$+\ 2^{nd} \text{ and } 3^{rd} \text{ order terms.}$$

The first term on the right-hand side of Eq. A-8 is clearly $E[A_{65}(I,R)]$,

To simplify Eq. A-8, the assumption is made that each error random variable in Eqs. A-7 is small in possible magnitude as compared to its associated expected value. Then to a "close" approximation (without specifying close) the random variable $A_{65}(I,R)$ equals the sum of its zeroth and first order terms.

<u>Assumption 2</u>. For any I,J, and R, the error terms $\delta\alpha_{65}(I,J,R)$, $\delta\beta_{65}(I,J)$, and $\delta P_{65}(I,J)$ are sufficiently small in possible magnitude with respect to $\bar{\alpha}_{65}(I,J,R)$, $\bar{\beta}_{65}(I,J,R)$, and $E[P_{65}(I,J)]$ respectively, that $A_{65}(I,R)$ is approximately,

$$A_{65}(I,R) \simeq E[A_{65}(I,R)]$$

$$+ {}_J\ \delta\alpha_{65}(I,J,R)\ \delta\beta_{65}(I,J)E[P_{65}(I,J)]$$

$$+ {}_J\ \bar{\alpha}_{65}(I,J,R)\ \delta\beta_{65}(I,J,R)\ E[P_{65}(I,J)]$$

$$+ {}_J\ \bar{\alpha}_{65}(I,J,R)\ \beta_{65}(I,J)\ \delta P_{65}(I,J).$$

In what follows this zeroth plus first order approximation to $A_{65}(I,R)$ will be assumed.

The error random variables δP_{65}, etc., will be small in possible magnitude with respect to their associated expected values ($E[P_{65}]$, etc.) if there is information available which gives the analyst quite certain information about their true values. In the case of P_{65}, a head count known to cover a substantial fraction of the total population would enable the analyst to assign a low variance distribution for δP_{65}. If an exact head count were available, the error random variable would equal zero. Quantitative discussion of the relationship between "closeness" and approximation accuracy will appear in a subsequent publication.

The task of calculating $Var[A_{65}(I,R)]$ will be eased by first determining the variance of some simple combinations of random variables. These simple results will then be applied to the more complicated task of finding $Var\ A_{65}(I,R)$. If Z is the sum of two random variables, X and Y, then,

$$\begin{aligned} Var\ [Z] &= E[Z - E[Z]]^2 \\ &= E[X - E[X] + Y - E[Y]]^2 \\ &= Var[X] + Var[Y] + 2\ Cov.[X,Y]. \qquad \text{(A-9a)} \end{aligned}$$

If random variables X and Y are independent, then the second term in Eq. A-9a will be zero. If $Z = XY$, where X and Y are random variables, then a first order Taylor approximation to Z is:

$$Z = E[X]\ E[Y] + E[Y](X - E[X]) + E[X](Y - E[Y]).$$

If the random variables X and Y are independent, then:

$$Var\ [Z] = E[Y]^2\ Var\ [X] + E[X]^2\ Var[Y]. \qquad \text{(A-9b)}$$

Now, whenever a sum of random variables is encountered, Equation A-9a can be applied; and if a product of random variables is encountered, Eq. A-9b can be applied.

The variance of $A_{65}(I,R)$ can be easily written using the operations indicated by Eqs. A-9a and A-9b. The result will contain a collection of covariance terms like $Cov[\delta\alpha_{65}(I,J_1,R), \delta\alpha_{65}(I,J_2,R)]$, and $Cov[\delta\alpha_{65}(I,J_1,R), \delta\beta_{65}(I,J_2,R)]$, etc. To make all these covariance terms zero, it is sufficient to assume that the random variables $\delta\alpha_{65}(I,J_1,R)$, $\delta\beta_{65}(I,J_2,R)$ and $\delta P_{65}(I,J_3,R)$ are pairwise independent. Since independence is not affected by translation, it is also sufficient to assume that $\alpha_{65}(I,J_1,R)$, $\beta_{65}(I,J_2,R)$ and $P_{65}(I,J_3,R)$ are pairwise independent.

<u>Assumption 3</u>. For any I, the collection of random variables $\alpha_{65}(I,J,R)$ for J = 1, 2, ...N_J; $\beta_{65}(I,J)$ for J = 1, 2, ...N_J; and $P_{65}(I,J)$ for J = 1, 2, ...N_J are pairwise independent.

The validity of this assumption for education R&D performance can be seen by looking at its implication in particular cases. Independence between $\alpha_{65}(I,J_1,R)$ and $\alpha_{65}(I,J_2,R)$, for example, holds if and only if knowledge of $\alpha_{65}(I,J,R)$ (ex., J = program directors and staff) does not change the estimated portion of work devoted to activity R in another job role (ex. J = hard core producers). Or, independence holds when, and if, knowledge of the portion of time devoted to activity R in work group (I,J), does not change the estimate of positions in another job role.

Applying the operations presented in Eqs. A-9a and A-9b to A-8--and using Assumptions 1, 2, and 3 many times, the final approximation for the variance of $A_{65}(I,R)$ is:

$$\begin{aligned}\mathrm{Var}[A_{65}(I,R)] = \sum_J \Big\{ & \mathrm{Var}[\bar{\alpha}_{65}(I,J,R)]\ (\bar{\beta}_{65}(I,J)E[P_{65}(I,J)])^2 \\ & + \bar{\alpha}_{65}{}^2(I,J,R)\mathrm{Var}[\beta_{65}(I,J)]E[P_{65}(I,J)]^2 \\ & + \bar{\alpha}_{65}{}^2(I,J,R)\bar{\beta}_{65}{}^2(I,J)\ \mathrm{Var}[P_{65}(I,J)] \Big\}. \end{aligned} \tag{A-10}$$

The standard deviation of $A_{65}(I,R)$ is related to its variance in the usual way:

$$\mathrm{Std}[A_{65}(I,R)] = (\mathrm{Var}[A_{65}(I,R)])^{\frac{1}{2}} \tag{A-11}$$

Equation A-11 and the data in Tables A-3, A-4, and A-5 were used to calculate the standard deviation of each estimate in Table A-2. The results are displayed alongside each corresponding value of $E[A_{65}(I,R)]$. Assuming that $A_{65}(I,R)$ is normally distributed, its true value lies between plus and minus one-half standard deviation of the mean quoted in Table A-2 with probability .37, within plus and minus one standard deviation of the mean with probability .63, and within plus and minus two standard deviations of the mean with probability .88.

The standard deviation of subtotals over activity classes and over institutional settings is also shown in Table A-2. The standard deviation of $A_{65}(I)$, the total activity in institutional setting I, is found by first summing $A_{65}(I,R)$ over all research activities; and then performing the variance calculation. Starting with Equation A-4 and using Equation A-3:

$$A_{65}(I) = \sum_J \beta_{65}(I,J)P_{65}(I,J). \qquad \text{(A-12a)}$$

The estimates of $A_{65}(I)$ are then:

$$E[A_{65}(I)] = \sum_J \bar{\beta}_{65}(I,J)\bar{P}_{65}(I,J), \text{ and} \qquad \text{(A-12b)}$$

$$\text{Var}\,[A_{65}(I)] = \sum_J \left\{ \bar{\beta}_{65}^{\,2}(I,J)\ \text{Var}[P_{65}(I,J)] + \text{Var}[\beta_{65}(I,J)]\bar{P}_{65}^{\,2}(I,J) \right\}. \qquad \text{(A-12c)}$$

Similarly, the subtotal of research activity over all institutional settings is:

$$A_{65}(R) = \sum_I A_{65}(I,R), \qquad \text{(A-13a)}$$

The estimate of $A_{65}(R)$ must then be:

$$E[A_{65}(R)] = \sum_I E[A_{65}(I,R)], \text{ and} \qquad \text{(A-13b)}$$

$$\text{Var}[A_{65}(R)] = \sum_I \text{Var}[A_{65}(I,R)]. \qquad \text{(A-13c)}$$

Appendix B

PERFORMERS OF EDUCATION R&D, FY 1968

BASIC MODEL

No direct count of total education RD&I manpower is available for FY 1968; thus, it is necessary to extrapolate from the 1965 results. The first assumption on which the analysis of this section will rest is that the bulk of the growth in man-years of education RD&I effort has been caused by increases in USOE and NSF funding. A second assumption on which analysis will rest is that the FY 1965 man-years table includes all education RD&I work supported by USOE or NSF in FY 1965.

Under these assumptions the basic model for man-years of performance in activity R in FY 1968 is to add the man-years of activity R supported by USOE or NSF in FY 1968 to the non-USOE, non-NSF supported man-years of activity R in FY 1965. This approach is feasible because detailed manpower and appropriations data are available for NSF and USOE for the years FY 1965 and FY 1968.

Under these two assumptions the model for man-years of activity in FY 1968 is:

$$A_{68}(I,R) = A_{68}(I,R,USOE + NSF) + \gamma(I,R).$$

$$\{A_{65}(I,R) - A_{65}(I,R,USOE + NSF)\} \qquad \text{(B-1)}$$

In Equation B-1, $\gamma(I,R)$ is the growth factor for non-USOE, non-NSF programs; $A_{68}(I,R,USOE + NSF)$ is the man-years of effort in FY 1968 supported by USOE or NSF; and $\bar{A}_{65}(I,R,USOE + NSF)$ is the same quantity for FY 1965. No data on the growth factors are available, but two reasonable assumptions will be made: (1) that $\gamma(I,R)$ is very close to 1 (the growth in non-USOE or non-NSF programs was small, and that (2) the growth factors are equal for all groups. The latter assumption is conservative in that perfect correlation between $\gamma(I,R)$'s produces greater variance in $A_{68}(I)$ than if the $\gamma(I,R)$'s were independent or imperfectly correlated. This will be shown shortly. The latter assumption implies that $\bar{\gamma}(I,R) = \bar{\gamma}$ for all I and R.

Mathematically, the first assumption is written as:

<u>Assumption 1</u>. $E[\bar{\gamma}(I,R)] = \bar{\gamma}(I,R) = 1 + \Delta(I,R)$ for all I and R, where $\Delta << 1$; and $\mathrm{Var}\ \{\gamma(I,R)\} << 1$.

Mathematically, the second assumption is written as:

<u>Assumption 2</u>. $\gamma(I,R) = \gamma$ for all work groups (I,R), where γ is an uncertain quantity.

As in the previous appendix, the estimate for the true value of $A_{68}(I,R)$ will be the expected value of $A_{68}(I,R)$; where

$$E[A_{68}(I,R)] = E[A_{68}(I,R,USOE + NSF)] + \bar{\gamma}$$
$$\{E[A_{65}(I,R)] - E[A_{65}(I,R,USOE + NSF)]\}. \qquad (B-2)$$

The uncertainty in estimating the true value of $A_{68}(I,R)$ will be described by quoting the variance of $A_{68}(I,R)$; where,

$$\mathrm{Var}[A_{68}(I,R)] = \mathrm{Var}[A_{68}(I,R,USOE + NSF)]$$
$$+ \bar{\gamma}^2\{\mathrm{Var}\ A_{65}(I,R) + \mathrm{Var}\ A_{65}(I,R,USOE + NSF)\}$$
$$+ \mathrm{Var}[\gamma]\ \{\bar{A}^2_{65}(I,R) + \bar{A}^2_{65}(I,R,USOE + NSF)\}. \qquad (B-3)$$

Equations B-2 and B-3 are the models used to obtain the final estimates of man-years of FY 1968 education RD&I activity shown in Table B-1.

Not all the inputs needed in Eqs. B-2 and B-3 are directly available in data sources. Estimates of $A_{65}(I,R)$ are available (Table A-2), but estimates of $A_{68}(I,R,USOE + NSF)$ and $A_{65}(I,R,USOE + NSF)$ are not. Developing these estimates is next on the agenda of this appendix.

<u>USOE AND NSF SUPPORTED PERFORMANCE IN FY 1968</u>

RD&I positions supported by USOE and NSF programs in FY 1966 and FY 1968 have been surveyed by Clark and Hopkins (1968; pp. 237, 238),

Table B-1

$A_{68}(I,R)$--RESEARCH ACTIVITY IN MAN-YEARS BY INSTITUTIONAL SETTING[1] FY 1968

	Basic and Mission-Oriented Research (R=1)		Development Activities (R=2)		Innovation Activities (R=3)		Subtotals	
	Mean*	Std+	Mean*	Std+	Mean*	Std+	Mean*	Std+
Colleges and Universities	1321	177	551	147	616	110	2493	214
Schools and Colleges of of Education	(618)	(223)	(377)	(112)	(285)	(76)	(1283)	(252)
Schools and Departments of Psychology	(203)	(85)	(70)	(42)	(52)	(29)	(325)	(94)
Other Behavioral and Social Science Depts	(206)	(117)	(160)	(49)	(66)	(22)	(432)	(127)
Other Discipline and Academic Areas	(102)	(57)	(246)	(119)	(57)	(45)	(405)	(156)
College and University Administration Areas	(76)	(38)	(64)	(35)	(16)	(41)	(156)	(49)
U. S. Office of Education	76	16	9	5	4	3	90	17
State Depts of Education and Other State Agencies	146	126	86	58	128	81	360	104
Schools and School Systems	320	85	479	110	137	53	935	139
Private Research Institutes and Agencies	129	76	126	75	28	81	283	108
Professional Education Associations	28	30	28	22	32	22	86	24
Other Professional, Public, and Lay Associations	21	14	232	103	57	34	310	122
Interagency Organizations and Educational Laboratories	72	44	675	140	96	44	845	132
Business and Industrial Organizations	39	20	77	35	29	18	144	53
Total	2037	501	2630	373	1300	272	5970	854

*$E[A_{68}(I,R)]$.

+Std = Standard Deviation of $A_{68}(I,R)$.

[1] Eqs. B-2 and B-3. Assume average growth in non-Federal programs is $\gamma = 1.00$ and Std(γ) = .15 (5 percent per year).

and are presented in Tables B-2 and B-3. To convert these data into the desired quantities (man-years of RD&I activity in FY 1965 and FY 1968), two steps are necessary: (1) to convert the FY 1966 position data into FY 1965 position data, and (2) to convert FY 1965 and FY 1968 position data into man-years of effort by research activity and institutional setting. Conversion of the FY 1968 positions data will be completed first.

The format of the data on positions in Tables B-2 and B-3 is slightly different than Table A-1, the positions table for all education R&D. In Tables B-2 and B-3, positions are reported as a function of institutional setting and Federal program instead of by institutional setting and job role. Thus, instead of the index J, the position data are conditioned on the newly defined index K, identifying the Federal program supporting a position.

Proceeding with reasoning similar to that in Appendix A, the expected man-years of USOE or NSF supported activity in work group (I,R) is related to positions in work group (I,K) by

$$A_{68}(I,R,USOE + NSF) = \sum_{K} \alpha_{68}^{OE}(I,K,R)\beta_{68}^{OE}(I,K)P_{68}(I,K,USOE + NSF) \tag{B-4}$$

where the summation is over Federal programs.

Directly relevant data for $\beta_{68}^{OE}(I,K)$ are not available but can be derived if it is assumed that the professional positions supported by Federal programs have an average cost of roughly $30,000 per man-year. Then, by dividing the amount of the FY 1968 appropriation for a work group by $30,000, times the number of positions supported in that work group, an estimate of the average man-years per position is obtained. As Table B-4 shows, many Federal programs have close to a $30,000 per man-year cost. Presumably, those which do not include a substantial portion of part-time effort.

Expressing this model in mathematical terms, assign $W_{68}(K)$ as the wage cost per professional position in Federal program, K. $W_{68}(K)$ is a random variable, since $30,000 per man-year is an uncertain figure. Then, if $B_{68}(K)$ is the USOE or NSF FY 1968 appropriation for program, K; and $P_{68}(K,USOE + NSF)$ is the number of

Table B-2

$E[P_{68}(I,k,USOE+NSF)]$, EXPECTED NUMBER OF POSITIONS IN USOE AND NSF SUPPORTED EDUCATION RESEARCH AND DEVELOPMENT, FY 1968

	Program K																	NSF		
	U. S. Office of Education[1]																			
	Centers					Instr. Materials	Educational Labs	ERIC Clearinghouses	Research Coord. Units	State Dept. Res. Divs.	Research			Development and Diffusion				Pre-college Course Content Improvement[1]	Teacher Institutes[2]	Subtotal
Institutional Settings, I	DEL	DCVR	DESR	HCY	Policy Study						Small	Regular	Special	Small	Regular	Special	Title III			
Colleges and Universities																			313	
Schools and Colleges of Education	360	78	56	12	3	41		107	44		170	285		52	192	77		83		1560
Schools and Departments of Psychology				3				12			28	101	12	2	14	9		31		212
Other Behavioral and Social Science Depts				4	5						24	172	12	7	28	9				261
Other Disciplines and Academic Departments				1				5			34	93	12	5	22	58		277		507
College and University Administration Units											4	5			1					10
State Departments of Education						25		8	131	324		7			6					501
Other State Agencies												12								12
Local Public Elementary and Secondary School Systems														7	9	5	910			931
Other Schools and School Systems												3								3
Private Research Institutes					11							37								48
Private Social Service and Welfare Agencies						20						9								29
Professional Education Associations								8												8
Related Professional, Public and Lay Ass'ns								23				3				40		216		282
Educational Laboratories							767													767
Subtotals	360	78	56	20	19	86	767	163	175	324	260	727	36	73	272	198	910	607	313	5131

[1] Set $E[P_{68}(I,K,USOE+NSF)]$ equal to positions reported in Clark and Hopkins, 1968, p. 238. Since authors of this source were very sure of their results (see Appendix B of source), assign $STD[P_{68}(I,K,USOE+NSF)] = .05 \times E[P_{68}(I,K,USOE+NSF)]$.

[2] Appendix C.

Table B-3

$E[P_{66}(I,k,USOE+NSF)]$, THE EXPECTED NUMBER OF USOE AND NSF SUPPORTED POSITIONS IN EDUCATION RESEARCH AND DEVELOPMENT PROGRAMS, FY 1966

	Program, K																			
	U. S. Office of Education[1]																	NSF		
	Centers							ERIC	Re-search	State Dept.	Research			Development and Diffusion				Pre-college Course	Teacher	
Institutional Settings, I	DEL	DCVR	DESR	HCY	Policy Study	Instr. Mater-ials	Educa-tional Labs	Clear-ing-Houses	Coord. Units	Res. Divs.	Small	Re-gular	Spe-cial	Small	Re-gular	Spe-cial	Title III	Content Improve-ment[1]	Insti-tutes[2]	Total
Colleges and Universities																			375	
Schools and Colleges of Education	334	39	56	12	3	32		64	57		208	319		64	369	77		70		1704
Schools and Departments of Psychology				3				7			34	114	12	3	27	9		26		235
Other Behavioral and Social Science Depts				4	5						29	192	12	8	53	9				312
Other Discipline and Academic Depts				1				3			41	105	12	6	43	58		235		[illegible]
College and University Administration Units											5	6			2					13
State Departments of Education						20		5	170	144		8			11					358
Other State Agencies												14								14
Local Public Elementary and Secondary School Systems														9	18	5	479			511
Other Schools and School Systems												3								3
Private Research Institutes					11							42								53
Private Social Service and Welfare Agencies						16						10								26
Professional Education Associations								5												5
Related Professional and Lay Associations								14				3				40		183		240
Educational Laboratories							285													285
Total	334	39	56	20	19	68	285	98	227	144	317	816	36	90	523	198	479	514	375	4263

[1] Set $E[P_{66}(I,K,USOE+NSF)]$ equal to positions reported in Clark and Hopkins, 1968, p. 238. Since authors of this source were very sure of their results (see Appendix B of source), assign $Std[P_{66}(I,K,USOE+NSF)] = .05 \times E[P_{66}(I,K,USOE+NSF)]$.

[2] Appendix C.

Table B-4

B_{68}(K)--APPROPRIATIONS IN FEDERAL PROGRAMS, FY 1968

Program, K	Appropriation[1] ($ millions) B_{68}(K)	[Std B_{68}(K)][3]	Positions[2] Mean*	Std+	Average Cost per Position ($ thousands)
USOE:					
Centers					
DEL	8.10		360	18	22.5
DCVR	2.23		78	4	28.5
DESR	1.70		56	3	30.4
HCY	.47		20	1	23.5
Policy Study	1.00		19	1	52.6
Instructional Materials	2.75		86	4	40.0
Laboratories	23.80		767	38	31.0
Clearinghouses	2.17		163	8	13.3
Research Coordinating Units	1.05		175	9	6.0
State Department Research Divisions	2.52	.25	324	16	7.8
Research					
Small	1.51		260	13	5.8
Regular	22.40		727	36	30.8
Special	1.00		36	2	27.8
D and D					
Small	.59		73	7	8.1
Regular	7.62		272	14	28.0
Special	5.50		198	10	27.8
Title III	16.70	1.67	910	46	18.4
NSF:					
Course Content Improvement	13.50		607	30	22.2
Teacher Institutes	38.30		313	16	30.0

*E [P_{68}(K,USOE+NSF)].

+Std = Standard deviation of P_{68}(K,USOE+NSF).

[1]Clark and Hopkins, 1968, p. 453.

[2]Table B-2.

[3]Except for Title V and III monies, appropriations are exact.

[4]Appendix C.

Table B-5

$\alpha_{68}^{OE}(I,K,R)$, THE DISTRIBUTION OF RESEARCH ACTIVITY BY FEDERAL PROGRAMS IN FY 1968[1]

Program, K	Research Activity, R: Basic and Mission-Oriented Research $\alpha_{68}^{OE}(I,K,1)$		Development Activities $\alpha_{68}^{OE}(I,K,2)$		Innovation Activities $\alpha_{68}^{OE}(I,K,3)$	
	Mean*	Std+	Mean*	Std+	Mean*	Std+
USOE:						
Centers						
DEL	.53	.06	.32	.06	.15	.05
DCVR	.33	.06	.18	.05	.49	.06
DESR	.50	.06	.34	.06	.16	.05
HCY	.50	.05	.30	.05	.20	.05
Policy Study	1.00					
Instructional Mtrs	.07	.05	.22	.08	.71	.08
Laboratories	.07	.05	.83	.06	.10	.05
Clearinghouses			.05	.05	.95	.05
Research Coordinating Units	1.00					
State Dept Research Divisions	.47	.08	.22	.07	.31	.07
Research						
Small	.97	.01	.02	.01	.01	.01
Regular	.85	.04	.11	.03	.04	.02
Special	1.00					
D and D						
Small	.19	.06	.70	.07	.11	.05
Regular	.27	.05	.53	.05	.20	.05
Special	.14	.05	.68	.06	.18	.05
Title III	.28	.06	.56	.06	.16	.05
NSF:						
Course Content Improvement			.83	.05	.17	.05
Teacher Institutes					1.00	

*$E[\alpha_{68}^{OE}(I,K,R)]$.

+Std = Standard deviation of $\alpha_{68}^{OE}(I,K,R)$.

[1]Mean values were set equal to data in Clark and Hopkins, 1968, p. 249. The standard deviations are subjective judgments of the author.

USOE or NSF supported positions; $\beta_{68}^{OE}(I,K)$ can be written as:

$$\beta_{68}^{OE}(I,K) = \frac{B_{68}(K)}{W_{68}(K)\ P_{68}(K,USOE + NSF)} \tag{B-5}$$

$B_{68}(K)$ instead of $B_{68}(I,K)$ appears in the numerator of Equation B-5, because appropriations data are available only as a function of Federal programs, and not institutional setting and Federal program.

The further assumption is made in Eq. B-5 that $\beta_{68}^{OE}(I,K)$ is constant over all institutional settings for a given Federal program, K. In mathematical language this means that the random variables $\beta_{68}^{OE}(I_1,K)$ and $\beta_{68}^{OE}(I_2,K)$ are equal for all values of I_1 and I_2. This is a conservative assumption, in that $Var[A_{68}(R)]$ will be larger than if the $\beta_{68}^{OE}(I,K)$'s were independent or partially dependent. The possible error from this assumption is small since, as Table B-2 shows, most of the work in a Federal program is performed in a single institutional setting.

Substituting Eq. B-5 into Eq. B-4 gives the transformation needed to convert data on positions into activity in work group (I,R,USOE + NSF).

$$A_{68}(I,R,USOE + NSF) =$$

$$\sum_K \alpha_{68}^{OE}(I,K,R)\ \frac{B_{68}(K)}{W_{68}(K)P_{68}(K,USOE+NSF)}\ P_{68}(I,K,USOE + NSF). \tag{B-6}$$

The true value of $A_{68}(I,R,USOE + NSF)$ is estimated by the expected value of $A_{68}(I,R,USOE + NSF)$, and this quantity will also be derived shortly.

$$E[A_{68}(I,R,USOE+NSF)] = \sum_K \alpha_{68}^{OE}(I,K,R)\ \frac{\bar{B}_{68}(K)E[P_{68}(I,K,USOE+NSF)]}{\bar{W}_{68}(K)E[P_{68}(K,USOE+NSF)]}. \tag{B-7}$$

The uncertainty in $A_{68}(I,R,USOE + NSF)$ is estimated by the variance of $A_{68}(I,R,USOE + NSF)$, and this quantity will also be derived shortly.

$$\mathrm{Var}[A_{68}(I,R,USOE{+}NSF)] = \underset{K}{} \{E[A_{68}(I,R,USOE{+}NSF)]\}.$$

$$\frac{\mathrm{Var}[\alpha_{68}^{OE}(I,K,R)]}{(\bar{\alpha}_{68}^{OE}(I,K,R))^2} + \frac{\mathrm{Var}[B_{68}(K)]}{\bar{B}_{68}^{\,2}(K)} + \frac{\mathrm{Var}[W_{68}(K)]}{\bar{W}_{68}^{2}(K)}$$

$$+ \frac{\mathrm{Var}[P_{68}(K,USOE{+}NSF)]}{(E[P_{68}(K,USOE{+}NSF)])^2} + \frac{\mathrm{Var}[P_{68}(I,K,USOE{+}NSF)]}{(E[P_{68}(I,K,USOE{+}NSF)])^2} \, . \qquad \text{(B-8)}$$

Equations B-7 and B-8 are the models used to generate the results in Table B-6. Most of the input data called for in these equations appear in Tables B-2 through B-5. Only data for $W_{68}(K)$ are missing.

As Table B-4 shows, many Federal programs cluster around $30,000 per position. Having this information, the a priori assumption will be made that $\bar{W}_{68}(K) = \$30{,}000$, and that the standard deviation of $W_{68}(K)$ is $\mathrm{Std}[W_{68}(K)] = \$4{,}500$. If knowledge about $W_{68}(K)$ is Gamma distributed, these assumptions imply that with probability .35 the true value of $W_{68}(K)$ is between $27,250 and $32,250 and with probability .90 between $21,000 and $39,000.

Data for $\alpha_{56}^{OE}(I,K,R)$ are only available as a function of program, K, and research activity, R; thus, the conservative[*] assumption is made that for a given program, K, the fraction, α_{65}^{OE}, of effort in research activity, R, is the same in each institutional setting (see Table B-5). With this assumption the subtotals of performance are, after summing Equation B-6 over all institutional settings:

$$E[A_{68}(R,USOE{+}NSF)] = \sum_{K} \bar{\alpha}_{68}^{OE}(K,R)\, \frac{\bar{B}_{68}(K)}{\bar{W}_{68}(K)}$$

and

$$\mathrm{Var}[A_{68}(R,USOE{+}NSF)] = \sum_{K} E[A_{68}(R,USOE{+}NSF)]^2 \, \cdot \qquad \text{(B-9)}$$

---

[*] The assumption is conservative in that the variance of $A_{68}(R, USOE{+}NSF)$ is greater than if the α_{65}'s were assumed identically distributed, but independent. The assumption has only a small effect on the final answer since, as Table B-2 shows, most of the performers in a Federal program work in a single institutional setting.

Table B-6

A_{68}(I,R,USOE+NSF)--RESEARCH ACTIVITY IN MAN-YEARS SUPPORTED BY FEDERAL PROGRAMS,[1] FY 1968

	Research Activity, R							
	Basic and Mission-Oriented Research (R-1)		Development Activities (R=2)		Innovation Activities (R=3)		Subtotals	
	Mean*	Std+	Mean*	Std+	Mean*	Std+	Mean*	Std+
Colleges and Universities	980	82	726	77	657	29	2362	126
Schools and Colleges of Education	(558)	(63)	(358)	(45)	(243)	(26)	(1159)	(75)
Schools and Departments of Psychology	(119)	(16)	(39)	(6)	(17)	(3)	(1758)	(17)
Other Behavioral and Social Science Depts	(185)	(27)	(146)	(21)	(38)	(8)	(368)	(35)
Other Discipline and Academic Areas	(112)	(15)	(182)	(23)	(46)	(9)	(340)	(30)
College and University Administration Areas	(5)	(1)	(1)				(7)	(1)
U. S. Office of Education								
State Depts of Education and Other State Agencies	79	12	30	8	53	9	162	18
Schools and School Systems	162	63	321	86	92	33	575	108
Private Research Institutes and Agencies	52	6	4	2	2	1	57	7
Professional Education Associations					4	1	4	1
Other Professional, Public, and Lay Associations	17	3	126	17	37	7	179	2
Interagency Organizations and Education Laboratories	56	41	659	140	79	42	793	132
Business and Industrial Organizations								
Total	1344	139	1866	180	923	99	4133	226

*E $[A_{68}(I,R,USOE+NSF)]$.

+Std = Standard deviation of A_{68}(I,R,USOE+NSF).

[1] Eqs. B-7 and B-8.

$$\left\{\frac{\mathrm{Var}[A_{68}(R,USOE+NSF)]}{\bar{B}^2_{68}(K)} + \frac{\mathrm{Var}[\alpha^{OE}_{68}(K,R)]}{\bar{\alpha}^2_{68}(K,R)} \left\{ + \frac{\mathrm{Var}[W_{68}(K)]}{\bar{W}^2_{68}(K)}\right\}\right.$$

The derivation of Eqs. B-7 and B-9 begins by writing the Taylor expansion for each term in Eq. B-6. Letting A_K be the K^{th} term in Eq. B-6, the zero and first order Taylor expansion of A_K is:

$$A_K = \left\{\bar{\alpha}^{OE}_{68}(I,K,R) \quad \frac{\bar{B}_{68}(K)E[P_{68}(I,K,USOE+NSF)]}{\bar{W}_{68}(K)E[P_{68}(K,USOE+NSF)]}\right\}\cdot$$

$$\left\{1 + \frac{\alpha^{OE}_{68}(I,K,R) - \bar{\alpha}^{OE}_{68}(I,K,R)}{\alpha_{68}(I,K,R)} + \frac{B_{68}(K) - \bar{B}_{68}(K)}{\bar{B}_{68}(K)}\right.$$

$$- \frac{W_{68}(K) - \bar{W}_{68}(K)}{\bar{W}_{68}(K)} - \frac{P_{68}(K,USOE+NSF) - E[P_{68}(K,USOE+NSF)]}{E[P_{68}(K,USOE+NSF)]}$$

$$\left. + \frac{P_{68}(I,K,USOE+NSF) - E[P_{68}(I,K,USOE+NSF)]}{E[P_{68}(K,USOE+NSF)]}\right\}. \tag{B-11}$$

The expected value of this Taylor expansion is:

$$E[A_K] = \frac{\bar{\alpha}^{OE}_{68}(I,K,R)\bar{B}_{68}(K)E[P_{68}(I,K,USOE+NSF)]}{\bar{W}_{68}(K)E[P_{68}(K,USOE+NSF)]} \tag{B-12}$$

and the variance of this approximation to A_K is:

$$\mathrm{Var}[A_K] = \left\{E[A_K]^2\right\}\cdot\left\{\frac{\mathrm{Var}[\alpha^{OE}_{68}(I,K,R)]}{(\alpha^{OE}_{68}(I,K,R))^2} + \frac{\mathrm{Var}[B_{68}(K)}{\bar{B}^2_{68}(K)} + \frac{\mathrm{Var}[W_{68}(K)]}{\bar{W}^2_{68}(K)}\right.$$

$$\left. + \frac{\mathrm{Var}[P_{68}(K,USOE+NSF)]}{(E[P_{68}(K,USOE+NSF)]^2} + \frac{\mathrm{Var}[P_{68}(I,K,USOE+NSF)]}{E[P_{68}(I,K,USOE+NSF)]}\right\}. \tag{B-13}$$

Taking the expected value of Eq. B-6 and substituting in Eq. B-12 gives Eq. B-7. Taking the variance of Eq. B-6 and substituting in Eq. B-13 gives Eq. B-8.

USOE AND NSF SUPPORTED PERFORMANCE IN FY 1965

The models of the previous section could also be used for estimating performance in FY 1965, except that position data for FY 1965 are not available. Position data for FY 1966, however, are available and are easily extrapolated back to FY 1965.

If $B_{65}(K)$ is the appropriation level of Federal program K in FY 1965, and $B_{66}(K)$ the same quantity for FY 1966, then it is reasonable to assume that the positions supported by a Federal program in FY 1965 are related to positions supported in FY 1968 by:

$$P_{65}(I,K,USOE+NSF) = \frac{B_{65}(K)}{B_{66}(K)} P_{66}(I,K,USOE+NSF), \tag{B-14}$$

where $B_{65}(K)$ is expressed in FY 1965 dollars. Since few FY 1966 programs existed in FY 1965, none were dropped, and none were increased by more than a small amount, Eq. B-14 is a reasonable model. It assumes no significant re-allocations were made in the USOE and NSF budgets between FY 1965 and FY 1966 other than to start new programs.

Using Eq. 4 as a parallel, the research activity supported by USOE or NSF in FY 1965 is:

$$A_{65}(I,R,USOE+NSF) = \sum_K \alpha_{65}^{OE}(I,K,R)\beta_{65}^{OE}(I,K)P_{65}(I,K,USOE+NSF). \tag{B-15}$$

Using Eq. B-7 as a parallel, $\beta_{65}^{OE}(I,K)$ is

$$\beta_{65}^{OE}(I,K) = \frac{B_{65}(K)}{W_{65}(K)P_{65}(K,USOE+NSF)} . \tag{B-16}$$

Then since $\sum_I P_{65}(I,K,USOE+NSF) = P_{65}(K,USOE+NSF)$, the research activity supported by USOE or NSF is

$$A_{65}(I,R,USOE+NSF) = \sum_K \alpha_{65}^{OE}(I,K,R) \frac{B_{65}(K)P_{66}(I,K,USOE+NSF}{W_{65}(K)P_{66}(K,USOE+NSF)} . \tag{B-17}$$

This equation was obtained by substituting Equations B-14 and B-16 into Equation B-15.

The expected value of $A_{65}(I,R,USOE+NSF)$ is,

$$E[A_{65}(I,R,USOE+NSF)] = \sum_K \bar{\alpha}_{65}^{OE}(I,K,R) \frac{\bar{B}_{65}(K)}{\bar{W}_{65}(K)} \cdot \frac{E[P_{66}(I,K,USOE+NSF)]}{E[P_{66}(K,USOE+NSF)]} ; \tag{B-18}$$

and the variance of $A_{65}(I,R,USOE+NSF)$ is,

$$\begin{aligned} Var[A_{65}(I,R,USOE+NSF)] = &\left\{E[A_{65}(I,R,USOE+NSF)]\right\}^2 \cdot \\ &\left\{ \frac{Var[\alpha_{65}^{OE}(I,K,R)]}{(\alpha_{65}^{OE}(I,K,R))^2} + \frac{Var[B_{65}(K)]}{\bar{B}_{65}^2(K)} + \frac{Var[W_{65}(K)]}{\bar{W}_{65}^2(K)} \right. \\ &\left. + \frac{Var[P_{66}(I,K,USOE+NSF)]}{(E[P_{66}(I,K,USOE+NSF)])^2} + \frac{Var[P_{66}(K,USOE+NSF)]}{(E[P_{66}(K,USOE+NSF)])} \right\} . \end{aligned} \tag{B-19}$$

The estimates of FY 1965 USOE or NSF supported research activity appearing in Table B-7 were calculated from Eqs. B-18 and B-19.

Some of the input data required by Eqs. B-18 and B-19 appears in Tables B-3, B-8, and B-9. In addition it was assumed that $\bar{W}_{65}(K) =$ \$25,800, which is $\bar{W}_{68}(K)$ deflated by 5 percent per year. As for FY 1968, it was assumed that Std. $W_{65}(K)] = .15\ \bar{W}_{65}(K)$.

Table B-7

A_{65}(I,R,USOE+NSF)--RESEARCH ACTIVITY IN MAN-YEARS SUPPORTED BY FEDERAL PROGRAMS, FY 1965[1]

Setting, I	Basic and Mission-Oriented Research (R=1) Mean*	Std+	Development Activities (R=2) Mean*	Std+	Innovation Activities (R=3) Mean*	Std+	Subtotals Mean*	Std+
Colleges and Universities	1095	161	362	103	486	85	1943	215
Schools and Colleges of Education	(521)	(93)	(136)	(50)	(61)	(17)	(717)	(88)
Schools and Depts of Psychology	(174)	(30)	(36)	(17)	(8)	(5)	(217)	(28)
Other Behavioral and Social Science Depts	(248)	(77)	(34)	(29)	(9)	(9)	(291)	(76)
Other Discipline and Academic Areas	(143)	(28)	(155)	(29)	(33)	(11)	(331)	(38)
College and University Administration Areas	(9)	(2)	(1)	(1)			(10)	(2)
U.S. Office of Education								
State Depts of Education and Other State Agencies	91	12	4	3	1.0	1.0	96	12
Schools and School Systems	4	1	1				4	1
Private Research Institutes and Agencies	53	11	7	6	2	2	62	10
Professional Education Associations								
Other Professional, Public, and Lay Associations	4	1	107	2	22	7	132	21
Interagency Organizations and Education Labs								
Business and Industrial Organizations								
Total	1248	202	481	131	510	94	2237	207

*E [A_{65}(I,R,USOE+NSF)].

+Std = Standard deviation of A_{65}(I,R, USOE + NSF).

1Eq. B-13.

Table B-8

$\alpha_{65}^{OE}(I,K,R)$--THE DISTRIBUTION OF RESEARCH ACTIVITY BY FEDERAL PROGRAM, FY 1965[1]

	Research Activity, R					
	Basic and Mission-Oriented Research $\alpha_{65}^{OE}(I,K,1)$		Development Activities $\alpha_{65}^{OE}(I,K,2)$		Innovation Activities $\alpha_{65}^{OE}(I,K,3)$	
	Mean*	Std+	Mean*	Std+	Mean*	Std+
USOE:						
Centers						
DEL	.53	.06	.32	.06	.15	.05
DCVR	.33	.08	.18	.07	.49	.09
DESR						
HCY						
Policy Study						
Instructional Materials						
Laboratories						
Clearinghouses						
Research Coordinating Units	1.00					
State Dept Research Divisions						
Research						
Small	.97	.03	.03	.03		
Regular	.85	.10	.12	.10	.03	.05
Special						
D and D						
Small						
Regular						
Special						
Title III						
NSF:						
Course Content Improvement			.83	.05	.17	.05
Teacher Institutes					1.00	

*$E[\alpha_{65}^{OE}(I,K,R)]$.

+Std = Standard deviation of $\alpha_{65}^{OE}(I,K,R)$.

[1] Mean Values were set equal to data in Clark and Hopkins, 1968, p. 249. The standard deviations are subjective judgments of the author.

Table B-9

$B_{65}(K)$--APPROPRIATIONS IN FEDERALLY SUPPORTED PROGRAMS, FY 1965

Program, K	FY 1966 Appropriations[1] ($ millions) $B_{66}(K)$	FY 1965 Appropriations[2] ($ millions) Mean*	Std+[3]	Average Cost per Position FY 1966[4] ($ thousands)
USOE:				
Centers				
DEL	6.79	2.17	.11	20.3
DCVR	1.00	1.32	.06	25.6
DESR	1.70			30.3
HCY	.47			23.5
Policy Study	1.00			52.6
Instructional Materials	1.00			14.7
Laboratories	8.03			28.1
Clearinghouses	1.54			15.7
Research Coordinating Units	2.15	2.18	.11	9.4
State Department Research Divisions	1.13			7.8
Research				
Small	1.67	2.40	.12	5.3
Regular	22.80	30.60	1.53	27.9
Special	1.00			27.7
D and D				
Small	.65			7.2
Regular	13.40			25.6
Special	5.50			27.7
Title III	6.00			12.5
NSF:				
Course Content Improvement	10.39	9.28	.46	20.2
Teacher Institutes		9.70		

*$E[P_{65}(I,K,USOE+NSF)]$.

+STD = Standard Deviation $P_{65}(I,K,USOE+NSF)$.

[1] Clark and Hopkins, 1968, Table 55, Col. 1.

[2] U.S. Office of Education, 1969 (in order of entry) pp. 116, 79, 78, 80, 78; reported by Bureau of Handicapped, USOE, pp. 116, 91, 79, ESEA Title V not authorized in FY 1965; total USOE research budget on p. 128, minus amounts already included above, split in same proportions as FY 1966 except "special" projects which did not exist; did not exist prior to ESEA passage FY 1966; reported by Precollege Division, NSF (see Appendix C).

[3] Assign a standard deviation of 5 percent of mean.

[4] See Table B-3 for positions data needed to calculate average cost.

Appendix C

NSF TEACHER INSTITUTE PROGRAMS

The data on NSF teacher institute programs called for in previous appendices is developed in this appendix. The form of the model needed to do this is tailored to the format of relevant NSF data.

The key items of NSF data are the appropriations for teacher institutes and the portion of each appropriation devoted to staff salaries. (The remaining cost of these programs is incurred as participant stipends, dependency allowances, and participant travel allowances.) Knowing the fraction spent on staff salaries, and assuming an average cost of roughly $30,000 per man-year of professional effort, the total professional man-years is simply the ratio of staff appropriations to man-year cost.

In mathematical terms, the total man-years of professional effort in teacher institute programs is

$$A_{68}^{TI} = \sum_{K} \frac{\Theta_{68}(K) B_{68}^{TI}(K)}{\bar{W}_{68}^{TI}} \qquad \text{(C-1)}$$

where $B_{68}^{TI}(K)$ is the annual appropriation for teacher institute program K, $\Theta_{68}^{TI}(K)$ is the fraction of program K spent on staff salaries, and W_{68}^{TI} is the staff cost per professional man-year. Again W_{68}^{TI} is assumed to be the same for all programs. The index K stands for one of two programs; NSF pre-college teacher institutes (K=1), or NSF teacher college institutes (K=2).

NSF data fix the values of $\Theta_{68}(K)$ and $B_{68}^{TI}(K)$, thus W_{68}^{TI} is the only uncertain quantity in Eq. C-1. Expanding Eq. C-1 in a Taylor series and proceeding as in Appendix B, it can be derived that

$$E[A_{68}^{TI}] = \sum_{K} \frac{\bar{\Theta}_{68}(K) \bar{B}_{68}^{TI}(K)}{\bar{W}_{68}^{TI}} \qquad \text{(C-2)}$$

and

$$\mathrm{Var}\ [A_{68}^{TI}] = \left\{ \sum_{K} \frac{\bar{\Theta}_{68}(K)\bar{B}_{68}^{TI}(K)}{\bar{W}_{68}^{TI}} \right\}^{2} \frac{\mathrm{Var}[W_{68}^{TI}]}{\bar{W}_{68}^{2}} \qquad \text{(C-3)}$$

The input data for $\bar{\Theta}_{68}(K)$ and $\bar{B}_{68}^{TI}(K)$ appear in Table C-1. It was assumed that $\bar{W}_{68}$ = $30,000 per man-year, and that Std $[W_{68}] = .15\ \bar{W}_{68}$ as in Appendix B. The resulting estimates of A_{68}^{TI} are shown at the bottom of Table C-1.

Since the purpose of NSF teacher institutes is to encourage the adoption of new science curricula, and not to develop new curriculum materials or do research, all man-years of effort and appropriations are assigned to the innovation category of research activity.

Table C-1

NSF TEACHER INSTITUTE PROGRAMS

	FY 1968		FY 1965	
	Pre-college (K=1)	College (K=2)	Pre-college (K=1)	College (K=2)
Appropriations for Teacher Institutes ($ millions) $\bar{B}^{TI}(K)$	34.2[1]	4.1[2]	35.3[3]	3.9[4]
Fraction of Appropriation Spent on Staff ($ millions) $B^{TI}(K)$	.23[5]	.40[6]	.23[5]	.40[6]
Amount Spent on Staff ($ millions)	7,8	1.6	8.1	1.6
Cost per Man Year[7] ($ thousands)	30,000	30,000	25,900	25,900
$\bar{W}^{TI}$	30,000	30,000	25,900	25,900
Standard Deviation Cost per Man Year[7] ($ thousands) $Std\left[W^{TI}\right]$	4,500	4,500	3,900	3,900
Expected Man-years in TI Programs $E\left[A^{TI}\right]$	313		375	
Standard Deviation of Man-years in TI Programs, $Std\left[A^{TI}\right]$	47		56	
Total Appropriations for TI Programs ($ millions)	38.3		39.4	

[1] National Science Foundation, 1969-1, p. 178.

[2] Ibid., p. 162.

[3] National Science Foundation, 1967, p. 97.

[4] Ibid., p. 113.

[5] U. S. Senate, 1969, p. 424.

[6] Ibid., p. 457.

[7] Author's judgment.

Appendix D

SPONSORSHIP OF EDUCATION RD&I IN FY 1968

The methods of Appendix A will also be used to describe the construction of tables for dollars spent in support of education RD&I. The basic model form is familiar by now; if $B_{68}(S,K)$ is the total appropriation spent by agency S on program K, and $\lambda_{68}(S,K,R)$ is the fraction spent on research activity R, then the amount spent on research activity R by agency S is the sum over all programs of $\lambda_{68}(S,K,R)$ times $B_{68}(S,K)$.

$$B_{68}(S,R) = \sum_{K} \lambda_{68}(S,K,R) B_{68}(S,K) \qquad \text{(D-1)}$$

Sufficient data are available to make reasonably certain estimates of $\lambda_{68}(S,K,R)$ and $B_{68}(S,K)$.

As an estimate of the true value of $B_{68}(S,R)$, the expected value is adopted:

$$\bar{B}_{68}(S,R) = \sum_{K} \bar{\lambda}_{68}(S,K,R) \bar{B}_{68}(S,K). \qquad \text{(D-2)}$$

The uncertainty in $B_{68}(S,R)$ is estimated by calculating its variance:

$$\mathrm{Var}\left[B_{68}(S,R)\right] =$$

$$\sum_{K} \left\{ \bar{\lambda}_{68}{}^{2}(S,K,R) \mathrm{Var}\left[B_{68}(S,K)\right] + \bar{B}_{68}{}^{2}(S,K) \mathrm{Var}\left[\lambda_{68}(S,K,R)\right] \right\}. \qquad \text{(D-3)}$$

The results obtained from the models written in Eqs. D-2 and D-3 appear in Table 10. The input data for these equations can be found in Table D-1.

Table D-1

APPROPRIATION TO AGENCIES FOR EDUCATION RD&I AND ITS DISTRIBUTION TO RESEARCH ACTIVITIES, FY 1968

Sponsoring Agency S; Program K	Basic and Mission-Oriented Research $\lambda_{68}(S,K,1)$		Development Activities $\lambda_{68}(S,K,2)$		Innovation Activities $\lambda_{68}(S,K,3)$		FY 1968 Appropriation $B_{68}(S,K)$ (millions)	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
USOE:[1] (S=1)								
Centers								
DEL	.53	.20	.32	.20	.15	.15	8.10	
DCVR	.33	.11	.18	.10	.49	.12	2.23	
DESR	.50	.20	.34	.20	.16	.14	1.70	
HCY	.50	.21	.30	.20	.20	.17	.47	
Policy Study	1.00						1.00	
Instructional Materials	.07	.07	.22	.15	.71	.15	2.75	
Laboratories	.07	.07	.83	.12	.10	.10	23.80	
Clearinghouses			.05	.05	.95	.05	2.17	
Research Coordinating Units	1.00						1.00	
State Department Research Divisions	.47	.21	.22	.17	.31	.20	2.52	.25
Research Projects								
Small	.97	.02	.02	.02	.01	.01	1.51	
Regular	.85	.06	.11	.05	.04	.04	22.40	
Special	1.00						1.00	
D and D Projects								
Small	.19	.10	.70	.10	.11	.07	.59	
Regular	.27	.10	.53	.11	.20	.09	7.62	
Special	.14	.08	.68	.11	.18	.10	5.50	
Title III	.28	.10	.56	.11	.16	.08	16.70	1.67
Intramural[2]	.85	.11	.10	.10	.05	.07	3.00	1.00
NSF: (S=2)								
Course Content Improvement								
Precollege[1]			.83	.10	.17	.10	13.50	
College[3]			.83	.10	.17	.10	6.00	
Teacher Institutes[4]					1.00		38.30	
OEO:[5] (S=3)								
Head Start	.30	.24	.40	.26	.30	.24	5.90	
Follow Through	.27	.20	.45	.24	.28	.20	2.20	
Community Action Program	.50	.28			.40	.28	4.70	
Other Federal Agencies:[6] (S=4)								
NIMH	.86	.03	.09	.02	.05	.02	14.10	10.00
NICHD	.91	.05	.09	.05			10.00	6.00
DOD	.67	.05	.33	.05			8.00	6.00
Other	.62	.06	.32	.05	.06	.02	7.00	5.00
State Government:[7] (S=5)	.33	.24	.33	.24	.33	.24	3.00	3.00
Foundations and Other:[8] (S=6)	.76	.06	.21	.05	.03	.03	14.00	10.00
Industry:[9] (S=7)	.40	.15	.50	.15	.10	.10	7.50	7.50

NOTES TO TABLE D-1

1. The mean values for $\lambda_{68}(S,K,R)$ were set equal to the data in Clark and Hopkins, 1968, p. 249. (See also Table B-5.) The standard deviations of $\lambda_{68}(S,K,R)$ were assigned somewhat larger than in Table B-5, since the Clark and Hopkins data are for positions, not appropriations. See Table B-4 for appropriations data.

2. See Tables A-1, A-2, A-4 and A-5. Assume that USOE expenditure is roughly $30,000 per professional man-year.

3. U. S. Senate, p. 445.

4. Appendix C.

5. U. S. Office of Education, 1969, p. 116. Following the definitions in this study, evaluation money is classed as development. Complete ignorance of the division of research and demonstration monies into research and innovation categories was assumed.

6. U. S. Office of Education, 1969, p. 129. Research training monies are not included. Evaluation and achievement studies are included as research. Demonstrations are included in innovation. All appropriations are increased 20 percent to account for non-respondents (Ibid, p. 117).

7. In Phillips, 1967, p. 76; total state agency expenditures for R&D were roughly $3.1 million in CY 1965 (Dimensions III and IV). Assuming half of this expenditure is financed by the state (National Science Foundation, 1967-2, p. 7), roughly $1.5 million of R&D activity was sponsored at the state level in 1965. The same NSF source, p. 31, reports $5.9 million was spent (or sponsored) by states in 1965. The chart entries for FY 1968 are based on these pieces of information. It is assumed that addition of ESEA Title V did not increase state support for R&D.

8. U. S. Office of Education, 1969, p. 129, As compensation for non-respondence, increase the value on p. 129 by 20 percent (Ibid, p. 117).

Appendix E

PERFORMANCE AND SPONSORSHIP OF AGRICULTURE RD&I, FY 1968

In agriculture, non-industrial RD&I performance and sponsorship in FY 1968 can be readily obtained from data published by the U. S. Department of Agriculture without the elaborate transformational steps required in education. Industrial RD&I performance and sponsorship can be estimated by extrapolating data published in FY 1966 to FY 1968, as was done for nonfederal education performance in Appendix B.

The format of the agriculture data is different from education or health in that, as part of a continuing program budgeting effort, USDA reports agricultural R&D activity in a hierarchical goal structure format. USDA has established up to 15 subgoals within each of 9 goals and reports R&D activity in each of these categories and subcategories. Few of these goals and subgoals can be translated into solely a research or solely a development activity, nor does USDA break down activity within goals or subgoals into RD&I classes. Consequently, subjective estimates must be made to get USDA data into the format of this study. These estimates have been based on worded descriptions of the activity in each goal.

The model used for transforming man-years of performance data in nonindustrial settings to the desired format is:

$$A_{68}(I,R) = \sum_{G} \kappa_{68}(I,G,R)A_{68}(I,G) \qquad \text{(E-1)}$$

where $A_{68}(I,G)$ is man-years of performance in institutional setting, I, and subgoal, G, and $\kappa(I,G,R)$ is the fraction of total man-years spent on research activity, R. As in Appendix A, independence between the κ's and the A_{68}'s is assumed. The true value of $A_{68}(I,R)$ is estimated by the expected value:

$$E\left[A_{68}(I,R)\right] = \sum_{G} \bar{\kappa}_{68}(I,G,R)E\left[A_{68}(I,G)\right]. \qquad \text{(E-2)}$$

The uncertainty in $A_{68}(I,R)$ is estimated by the variance:

$$Var\left[A_{68}(I,R)\right] =$$

$$\sum\left\{\bar{\kappa}_{68}{}^2(I,G,R)Var\left[A_{68}(I,G)\right] + E\left[A_{68}(I,G)\right]^2 Var\left[\kappa_{68}(I,G,R)\right]\right\} \qquad (E\text{-}3)$$

Input data for the models written as Eqs. 2 and 3 appear in Table E-1. The results of these models appear in Table 4.

The data for $\kappa_{68}(I,G,R)$ were assigned by examining a USDA list of project areas in each goal. If 20 out of 30 project areas in a goal were classed as research, then $\bar{\kappa}_{68}(I,G,R) = .66$ was assigned, etc. In making these assignments, the definitions in Table 2 were utilized. Since the level of effort in each project area was not quoted in the USDA list a high value was assigned for the standard deviation of $\kappa_{68}(I,G,R)$.

As mentioned in the first paragraph, activity data for the industrial setting (I = 4) have been published by USDA for FY 1965, but not for FY 1968. Letting $\gamma^{Ag}(G)$ be the growth factor of industrial R&D in goal G between FY 1965 and FY 1968, $A_{68}(4,G)$ can be written as:

$$A_{68}(4,G) = \gamma^{Ag}(G)A_{65}(4,G) \qquad (E\text{-}4)$$

where $A_{65}(4,G)$ is the man-years of performance in FY 1965. As in Appendix A, make the conservative assumption that $\gamma^{Ag}(G)$ is the same in each goal, then,

$$E\left[A_{68}(4,R)l\right] = \bar{\gamma}^{Ag}\sum_G \bar{\kappa}_{68}(4,G,R)E\left[A_{65}(4,G)\right] \qquad (E\text{-}5)$$

and

$$Var\left[A_{68}(4,R)\right] = Var\left[\gamma^{Ag}\right]\left\{\sum_G \kappa_{68}(4,G,R)E\left[A_{65}(4,G)\right]\right\}^2 +$$

$$(\bar{\gamma}^{Ag})^2\sum_G\left\{\bar{\kappa}_{68}{}^2(4,G,R)\ Var\left[A_{65}(4,G)\right] + E\left[A_{65}(3,G)\right]^2 Var\left[\kappa_{68}(4,G,R)\right]\right\} \qquad (6)$$

In calculating results from Eqs. 5 and 6, assume $\bar{\gamma}^{Ag} = 1$, which means that industrial R&D is estimated not to have grown at all between FY 1965 and FY 1968. From Table 16 in Chapter 5, it is apparent that federally sponsored performance changed very little from FY 1965 to FY 1968. This result is assumed to carry over into industrial R&D. Recognizing the maturity of agricultural R&D, this assumption seems reasonable.

Since estimates of the $\kappa_{68}(I,G,R)$s were based on an aggregate of data for USDA and SAES, the degree of correlation between the one for USDA $\left(\kappa_{68}(1,G,R)\right)$, and for SAES $\left(\kappa_{68}(2,G,R)\right)$ will be high. As a conservative measure assume perfect correlation. Then,

$$E\left[A_{68}(R)\right] = \sum_{G}\left\{\bar{\kappa}_{68}(1,G,R)\sum_{I=1}A(I,G) + \bar{\kappa}_{68}(4,G,R)A(4,6)\right\} \qquad (7)$$

and

$$\mathrm{Var}\left[A_{68}(R)\right] =$$

$$\sum_{G}\left\{\bar{\kappa}^{2}_{68}(1,6,R)\sum_{I=1}^{2}\mathrm{Var}\left[A(I,6)\right] + \mathrm{Var}\left[\kappa_{68}(1,6,R)\right]\left(\sum_{I=1}^{2}E\left[A(I,6)\right]\right)^{2} + \right.$$

$$\left.\bar{\kappa}^{2}_{68}(4,6,R)\mathrm{Var}\left[A_{68}(4,6)\right] + \mathrm{Var}\left[\kappa_{68}(4,6,R)\right]\cdot E\left[A(4,6)\right]^{2}\right\}. \qquad (8)$$

The results obtained from these equations appear in Table 4.

Substituting $B_{68}(S,6)$ for $A_{68}(I,6)$, and $\gamma_{68}(S,6,R)$ for $\kappa_{68}(I,G,R)$, these same equations apply also for agriculture sponsorship. Input data and results for agriculture sponsorship appear in Table E-2, and in Table 9.

Table E-1

INPUT DATA AND RESULTS FOR RD&I PERFORMANCE, FY 1968

Institutional Setting I and Goal G	Fraction of Effort in Research $\kappa_{68}(I,G,1)$[5]		Man-Years of Effort $A_{68}(I,G)$		Man-Years in Research $A_{68}(I,R=1)$[6]	
	Mean	Std	Mean	Std	Mean	Std
USDA[1] (I=1)			4,319.4	300	2085.0	356.8
G=1	.55	.20	800.3			
G=2	.44	.20	1,028.6			
G=3	.33	.20	621.5			
G=4	.40	.20	977.1			
G=5	.76	.15	322.2			
G=6	.77	.15	75.8			
G=7	.59	.20	180.3			
G=8	.67	.20	139.5			
G=9	.54	.20	174.0			
Colleges and Universities[2] (I=2)			9,551.0	50	2359.8	525.7
G=1	.55	.20	541.4			
G=2	.44	.20	1197.3			
G=3	.33	.20	2155.6			
G=4	.40	.20	506.4			
G=5	.76	.15	227.3			
G=6	.77	.15	19.4			
G=7	.59	.20	190.6			
G=8	.67	.20	122.8			
G=9	.54	.20	442.0			
Ag Extension[3]			4000	50		
County Agencies[4] (I=3)						
Ag Extension			11,000	275		
Industry[5] (I=4)			15,900	1564	7950.0	2359.0
G=1	.50	.28	600	120		
G=2	.50	.28	4,000	800		
G=3	.50	.28	4,000	800		
G=4	.50	.28	5,250	1050		
G=5	.50	.28	700	140		
G=6	.50	.28	250	50		
G=7	.50	.28	800	160		
G=8	.50	.28	100	20		
G=9	.50	.28	200	40		
Total			40,620	1590	12,396.0	2443.1

[1]U.S. Department of Agriculture, 1969, Table III-D-8.

[2]Ibid., Table IV-C-9.

[3]Data reported by USDA in private conversation. Assume all man-years are innovation.

[4]Data reported by USDA in private conversation.

[5]Equation E-4 and U.S. Department of Agriculture, 1966, p. 8. Data based on SIE survey. Assume no knowledge of the split between research and development.

[6]The man-years data in the above sources are for R&D only. Thus $\kappa_{68}(I,G,3) = 0$.

[7]Equations E-8 and E-9.

Table E-2

INPUT DATA AND RESULTS FOR AGRICULTURE RD&I SPONSORSHIP, FY 1968

Sponsor S and Goal G	Fraction of Sponsorship in Research[1] $\mu_{68}(I,G,1)$		Total Sponsorship[2] ($ millions) $B_{68}(S,6)$		Fraction of Research Sponsorship[3] ($ millions) $B_{68}(S,R=1)$	
	Mean	Std	Mean	Std	Mean	Std
USDA (S=1)			303.2	0	97.8	17.7
G=1	.55	.20	33.3			
G=2	.44	.20	54.7			
G=3	.33	.20	43.6			
G=4	.40	.20	39.8			
G=5	.76	.15	12.6			
G=6	.77	.15	1.7			
G=7	.59	.20	10.3			
G=8	.67	.20	5.0			
G=9	.54	.20	9.1			
Ag Extension			93.5			
State Government			121.8	0	50.8	13.0
G=1	.55	.20	10.8			
G=2	.44	.20	28.5			
G=3	.33	.20	55.6			
G=4	.40	.20	10.8			
G=5	.76	.15	2.4			
G=6	.77	.15	.3			
G=7	.59	.20	2.9			
G=8	.67	.20	2.0			
G=9	.54	.20	8.5			
Ag Extension			147.5			
Industry			460.0	45.1	230.0	69.3
G=1	.5	.28	17.0	3.4		
G=2	.5	.28	115.0	22.0		
G=3	.5	.28	115.0	22.0		
G=4	.5	.28	160.0	32.0		
G=5	.5	.28	15.0	3.0		
G=6	.5	.28	8.0	1.6		
G=7	.5	.28	22.5	4.5		
G=8	.5	.28	1.5	.3		
G=9	.5	.28	6.0	1.2		
Total			1032.5	45.1	378.6	72.7

[1]Assume same values as for $\kappa_{68}(I,G,1)$ in Table E-1.

[2]U. S. Department of Agriculture, 1967, Tables III-D-8 and IV-C-9. Ibid., 1966, p. 56 for industry.

[3]Equations E-7 and E-8.

Appendix F

PERFORMANCE AND SPONSORSHIP OF HEALTH RD&I, FY 1968

RD&I performance and sponsorship in health can be obtained from data that have been collected by the Office of Resource Analysis at NIH. These data are not divided into research and development classes, but sufficient auxiliary information is available to divide the sponsorship data into these two classes. Information which would enable the same division on the performance side is not available.

For performance, the NIH data give dollars spent by sponsor S, and the distribution of these funds by performing institutions. Therefore, the dollars consumed in an institutional setting can be found by summing the portion of funds contributed to an institutional setting over all sponsors. The total man-years of effort can then be found by dividing by the cost per man-year.

In mathematical terms, the man-years of effort in institutional setting I is related to dollars of sponsorship by

$$A_{68}(I) = W_{68}^{-1}(I) \sum_S \rho(I,S) B_{68}(S) \qquad \text{(F-1)}$$

where $B_{68}(S)$ is the dollars contributed by sponsor S and $\rho(I,S)$ is the fraction consumed in institutional setting I. The rate $W_{68}(I)$ is the cost of RD&I activity per man-year in institutional setting, I.

Considering all quantitites in Eq. F-1 as uncertain, the estimates of performance are:

$$E\left[A_{68}(I)\right] = \left(\bar{W}_{68}(I)\right)^{-1} \sum_S \bar{\rho}_{68}(I,S) E\left[B_{68}(S)\right] \qquad \text{(F-2)}$$

and,

$$\mathrm{Var}\left[A_{68}(I)\right] = \frac{\mathrm{Var}\left[W_{68}(I)\right]}{\bar{W}_{68}^{\,4}(I)} \left(\sum_S \bar{\rho}_{68}(I,S) E\left[B_{68}(S)\right]\right)^2 +$$

$$\left(\bar{W}_{68}(I)\right)^{-2} \sum_S \left\{ \bar{\rho}^2(I,S) \mathrm{Var}\left[B_{68}(S)\right] + E\left[B_{68}(S)\right]^2 \mathrm{Var}\left[\rho_{68}(I,S)\right] \right\} . \qquad \text{(F-3)}$$

Input data for these equations appear in Table F-1. None of the sponsor's money in Table F-1 was spent on innovation activities; thus, the resulting estimates are for R&D activity only. No attempt was made to estimate performance in innovation activities, although some surely exists in the health field.

The NIH data can be used directly to estimate sponsorship. In addition, auxiliary data sources can be used to estimate the breakdown of the sponsorship totals into money for development and for research.

The models for estimating the dollars spent by sponsor S for activity R are:

$$E\left[B_{68}(S,R)\right] = \bar{\tau}_{68}(S,R)E\left[B_{68}(S)\right], \tag{F-4}$$

and

$$\mathrm{Var}\left[B_{68}(S,R)\right] = \bar{\tau}^{2}_{68}(S,R)\mathrm{Var}\left[B_{68}(S)\right] + \mathrm{Var}\left[\tau_{68}(S,R)\right]E\left[B_{68}(S)\right]^{2} . \tag{F-5}$$

The input data for these models appear in Table F-2.

The estimates of $\tau_{68}(S,R)$ in Table F-2 are based on NIH and NSF information. For the drug industry and all agencies except one, the sum of monies each spent on basic and applied research in health-related fields of science (which has been tallied by NSF) is less than the total health-related R&D (which has been tabulated by NIH). Thus, it would be natural to estimate expenditures for development as the difference between these numbers. On the basis of discussion with NIH analysts, however, apparently some of the applied research would be classed as development under the definitions adopted here. Consequently, estimates of $\tau_{68}(S,R)$ were assigned for government agencies in the following ways. All of the basic research plus one-half of the applied research was expressed as a fraction of the total health-related R&D. The result was assigned as $\bar{\tau}(S,R)$. The estimate of Std $\tau_{68}(S,R)$ was set equal to one-fourth of the applied research expressed as a fraction of total R&D.

Table F-1

INPUT DATA FOR PERFORMANCE OF HEALTH R&D, FY 1968

	$\tau_{68}(I,S)$, Fraction of S's Dollars Spent in Institutional Setting I[b]											
	Federal Laboratory (I=1)		Universities and Colleges (I=2)		Non-Profit Institutions (I=3)		Industry (I=4)		Other Performers (I=5)		Sponsorship ($ millions) $B_{68}(S)$[6]	
Sponsor, S	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
NIH[1]	.16		.60		.15		.04		.05		863.9	
Other DHEW[2]	.25		.40		.19		.03		.14		264.0	
Veterans Admin.[3]	.98		.01		.01						46.0	
Other Federal[2]	.32		.33		.07		.26		.02		353.0	
State and Local[2,3]			.15	.15	.10	.10	.10	.10	.65	.21	69.0	6.9
Industry[3,4]			.05	.05	.05	.90	.07				615.0	62.0
Private Support[2,4]			.50	.28	.50	.28					185.0	19.0
Total Expenditure ($ millions)	362.3		874.5	69.9	335.1	61.5	694.7	70.1	139.0	15.4	2395.6	64.3
Cost Per Man Year[5] ($ thousands) $W_{68}(I)$	35.0	3.5	36.3	3.6	36.3	3.6	65.0	6.5	33.0	3.3	40.9	3.0
R&D Man Years $A_{68}(I)$	10,350	1035	24,900	2940	9230	1924	10,687	1518	4211	628	58,570	4010

[1] U. S. House of Representatives, 1971, pp. 43-44.

[2] Distribution of sponsor's dollars to performers is obtained from unpublished NIH data.

[3] National Science Foundation, 1969-4, p. 10 for information on the distribution to performers.

[4] The distribution of sponsor's funds is assumed.

[5] U. S. Office of Resource Analysis, p. 37. Data are for positions. As an estimate of $\overline{W}_{68}(I)$, increase the data in this source by 10 percent. Standard deviation is assumed.

[6] Table F-2.

Table F-2

INPUT DATA FOR SPONSORING HEALTH R&D, FY 1968

Sponsor, S	$\tau_{68}(S,I)$ Fraction of Sponsor's Dollars Spent on Research — Mean	Std	$B_{68}(S)$ of Dollars Sponsorship[2] (millions) — Mean	Std	$B_{68}(S,R=1)$ Dollars Spent on Research (millions) — Mean	Std
NIH[1]	.70	.15	864.0		605.0	130.0
Other DHEW	.43	.11	264.0		113.5	29.0
Consumer Protection			(78.3)		(36.0)[3]	
HSMA			(146.7)		(68.4)[3]	
Other			(39.3)		(9.4)[3]	
Vet. Administration	.55	.20	45.6		25.1[3]	9.0
DOD	.67	.19	114.0		76.4[3]	21.7
AEC	.78	.03	95.0		74.1[3]	2.9
NASA	.84	.06	109.0		91.6[3]	5.4
NSF	1.00		21.0		21.0	
Dept. Commerce	.5	.28	1.0		.5	.3
Dept. Interior	.5	.28	3.0		1.5	.8
Dept. State	.5	.28	3.0		1.5	.8
Dept. Transportation	.15	.15	5.0		.8[3]	.8
TVA	.40	.20	2.0		.8[3]	.4
State (Local)	.50	.28	69.0	6.9	34.5	19.6
Industry[4]	.38	.11	615.0	61.0	233.7	71.5
Foundation and Institutional Funds[5]	.90	.10	185.0	19.0	166.5	25.2
Total			2395.6	65.5	1446.2	156.1

[1] National Institutes of Health, 1969, p. 9. See also, last paragraph of Appendix F.

[2] U. S. House of Representatives, 1971, pp. 43-44.

[3] National Science Foundation, 1969-2. To get $\bar{B}_{68}(S,R=1)$ add data from p. 170 (Biological Aspects and Psychological Sciences), and p. 173 (Life Sciences), plus one-half of data on p. 195 (Biological Aspects and Psychological Sciences) and p. 198 (Life Sciences).

[4] National Science Foundation, 1969-4, p. 64, for information on $\tau_{68}(S,1)$.

[5] Author's judgment.

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